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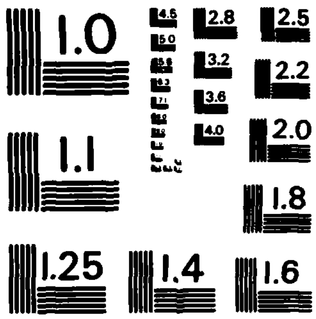
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Program Engineering
and Maintenance Service
Washington, D.C. 20591

Heliport Snow and Ice Control Methods and Guidelines

AD-A148 137

John B. McKinley
Robert B. Newman

Systems Control Technology, Inc.
West Palm Beach, Florida 33406

August 1984

Final Report

This Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/PM-84/22	AD-A148137	

4. Title and Subtitle	5. Report Date
HELIPORT SNOW AND ICE CONTROL METHODS AND GUIDELINES	August 1984
	6. Performing Organization Code
7. Author(s) J.B. McKinley and R.B. Newman	8. Performing Organization Report No.
9. Performing Organization Name and Address Systems Control Technology Inc. 2326 So. Congress Avenue, Suite 2-A West Palm Beach, Florida 33406	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFA01-80-C-10080
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code APM-720

15. Supplementary Notes

16. Abstract

Guidelines for snow and ice control on heliports are presented for the purpose of both enhancing the operational utility of heliports, and employing the unique capabilities of the rotorcraft to the maximum extent. These guidelines consider manual methods of snow and ice control such as plowing and chemical application, and automated methods through pavement heating systems. Cost and design considerations are provided for each system. Benefit/cost decision guidelines are provided with estimated annual operating cost data for 32 U.S. cities, and six snow and ice control methods. In addition, selection guidelines provide a methodology to assist heliport planners and designers with the selection of the most appropriate snow and ice control system.

17. Key Words	18. Distribution Statement
HELIPORT SNOW ICE DEICING CHEMICALS PAVEMENT HEATING SYSTEMS	This document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	59	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The Aircraft Safety and Airport Technology Division, Program Engineering and Maintenance Service of the Federal Aviation Administration sponsored this engineering study to develop guidelines for the use and design of various heliport snow and ice control methods. This effort was performed by Systems Control Technology, Inc., Champlain Technology Industries Division, under Contract Number DTFA01-80-C-10080, Task F-2, Modification No. 0031.

The FAA Technical Monitor for this study was Mr. Norman Fujisaki, APM-720. The Project Manager for this effort was Mr. John McKinley, and the principal investigator was Mr. Robert Newman, both of the SCT/CTI staff.

The scope of the tasks performed during this study included a comprehensive literature review regarding airport and highway snow and ice control, and much correspondance and many conversations with manufacturers, architects, heliport/airport operators and planners. Documentation was prepared on guidelines for selection, use of, and design of various snow and ice control methods for heliports. This study's period of performance was approximately eight calender months.

Many important contributions to this effort were provided by a number of individuals, manufacturers and firms. Among these contributors, SCT wishes to express sincere thanks to Adams Architects and Planners of Denver, Colorado; SETA Corporation of Laramie, Wyoming; Easy Heat-Wirekraft of New Carlise, Indiana; Bio-Energy Systems, Inc. of Ellenville, New York; and the Allentown-Bethlehem-Easton Airport, Leigh-North Hampton Airport Authority.

Finally, special thanks is extended to Mrs. Judy Weaver and Ms. Keelie Cinefra for the arduous task of typing and edit typing.

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The organization of this report is divided into several sets of guidelines, including guidelines for use of various snow and ice control methods, design guidelines for pavement heating systems, benefit/cost decision guidelines, and snow and ice control method selection guidelines. To assist the reader in correlating the content of the remainder of the summary to the major sections of the report, the following subjects are addressed in the corresponding sections:

TOPICS	SUMMARY	DETAILS
Snow and Ice Control - General Considerations	1.2	2.0
Snow and Ice Control Techniques	1.3	3.0*
Benefit/Cost Decision Guidelines	1.4	4.0*
Selection Guidelines	1.5	5.0*
Conclusions and Recommendations	1.6	6.0

*Guidelines Provided

1.1 BACKGROUND

The impetus for this engineering study relates to the FAA's anticipated demand and growth in IFR heliports and IFR and special VFR helicopter operations. The FAA responded to the unprecedented growth in the helicopter industry by establishing the Rotorcraft Program Office (RPO). In order to foster the specific needs of rotorcraft aviation, the Rotorcraft Master Plan[4] (RMP) was implemented. The RMP addresses the specific needs of rotorcraft in the areas of certification, heliports, and the National Airspace System (NAS) through the year 2000.

To realize the full potential of the rotorcraft and to employ their unique capabilities to the fullest extent, the RMP has established a goal of developing 25 major urban VFR/IFR heliports by the year 2000. This goal leads to another RMP goal of updating and streamlining the rotorcraft icing certification standards, procedures, and guidelines. This enhancement will allow rotorcraft to utilize VFR/IFR heliports during freezing IMC. Since heliports are likely to have snow and ice accumulation during such conditions, there is an explicit need for heliport snow and ice control guidelines.

1.2 SNOW AND ICE CONTROL - GENERAL CONSIDERATIONS

Of the many different techniques and methods that may be used for heliport snow and ice control, the proven manual approach, employing brooms, shovels and small plows, is the most common solution today.

In general, there are three considerations involved in selecting a snow and ice control method appropriate to a particular heliport: expediency and safety, increased helicopter operations, and cost. An evaluation of these considerations is useful in characterizing a heliport.

Safety considerations include ground personnel, ingressing and egressing passengers and crew, and the helicopter itself. The not so obvious consideration for the helicopter relates to the phenomenon termed "white-out", produced by rotor downwash collecting snow and obscuring the pilot's vision.

Increased helicopter operations for VFR heliports is not usually a deciding factor for reducing heliport snow and ice removal time. Typically, large accumulations of snow, requiring several hours to remove manually, often occur during IMC when the VFR heliport is closed and when non-icing certified helicopters are not flying. Therefore snow and ice control methods that dramatically reduce the length of time heliport is closed are more applicable to future IFR heliports than today's VFR heliports, unless the VFR heliports can accommodate more special VFR operations.

Costs associated with the various snow and ice control methods that are not normally considered include mechanical equipment, chemical dry storage, and possibly maintenance and cleaning equipment. Pavement heating systems have additional expenses for preparing the landing pad pavement and substructure.

Climatological considerations are also useful in characterizing where various snow and ice control methods function best. In general, mechanical methods (i.e., plowing) are suitable in any region where snow accumulates frequently during the winter months. This is typically where annual snow loads are greater than 5 lbs/ft^2. Plowing is also preferred in regions where temperatures remain below 15°F, since chemical application and pavement heating systems are not as suited to these extremes. Furthermore the difference between ground level and elevated heliport snow and ice accumulation is discussed. Mechanical augmented with chemical application and pavement heating methods tend to suit climates where the annual snow load is higher than 5 lbs/ft^2 and temperatures greater than 15°F.

1.3 SNOW AND ICE CONTROL TECHNIQUES

There are three techniques (mechanical, mechanical/chemical and pavement heating) available to a heliport manager to keep a helipad clear of snow and ice. Each technique has advantages and disadvantages which must be evaluated against each heliports expected operations. Mechanical snow removal is the familiar snow plow and/or snow blower that most operators are using today. Mechanical/chemical snow removal utilizes a material noncorrosive to aircraft, such as urea or ethylene glycol, to break the ice to surface bond and facilitating mechanical removal of ice buildup. Pavement heating systems involve placing a heat distribution system inside the helipad and maintaining the temperature of the pad above the freezing point of water.

Section 3.0 through 3.3.2 provides specific guidelines for the use of mechanical, mechanical/chemical, and pavement heating system techniques for controlling snow and ice on helipads. Various mechanical means for controlling snow and ice are mentioned as well as techniques for removing ice. Considerations for use of dry and liquid chemicals are presented along with typical application rates.

In addition to the use of pavement heating systems, Sections 3.3.1 and 3.3.2 present details and guidelines for the design of various pavement heating systems.

Associated with the design considerations, Sections 3.3.1 provides a cost comparison of various snow and ice control methods, including mechanical and chemical, for a heliport in the Boston, Massachusetts area.

1.4 BENEFIT/COST DECISION GUIDELINES

Benefit/cost decision guidelines are provided to assist in selecting the most suitable snow and ice control method as a function of snow removal systems, cost of heliport operations, and geographic location.

Presented in Section 4.0 is a means for identifying annual heliport benefits that may be lost, totally or in part, due to the heliport being closed during and subsequent to snowfall and/or icing conditions.

On the other side of the benefit/cost equation, operating costs for various snow and ice control methods are provided for 32 cities in the U.S. Procedures are described for using the cost estimates to produce a benefit/cost ratio to indicate whether a particular method is justifiable for the heliport being considered.

1.5 SELECTION GUIDELINES

In the event that the heliport planner has difficulty in selecting the most appropriate snow and ice control method, selection guidelines are presented. These guidelines are based on the content of Section 2.2 and 4.0. These sections, respectively, identify climatological aspects, and describe a means of comparatively evaluating the costs of snow and ice control methods.

The selection guidelines prompt evaluation of a number of factors to lead to a choice between mechanical, mechanical/chemical, or pavement heating systems. They do not provide for specific delineation between pavement heating systems. This can be accomplished by the procedures described in Section 4.0.

The guideline decisions are based on determinant factors such as, safety, climatology, IFR operations,and time and dollar budgets. These determinant factors, or decision points, are organized in such a manner to lead the planner to a logical choice.

Heliport planners experiencing high operating costs, frequent helicopter operations, and providing many services aimed at helicopter operators will probably realize the necessity of a logical selection

process. This is especially true if the proper selection may result in increased operations, greater heliport utility, and ultimately greater profits.

1.6 CONCLUSIONS

The following conclusions are based on the results of a comprehensive engineering study and detailed telephone discussions with heliport operators, architects, and planners:

PRIMARY CONCLUSIONS:

1) The majority of the heliports in the U.S., located in regions having annual snowfall activity, do not presently have a sufficient number of helicopter operations to justify the expense of a pavement heating system.

2) The most common method of snow and ice removal is mechanically, by means of shovels, brooms, and truck or small lawn tractor mounted plows.

3) Chemical application is not a common method for ice control. It is used in conjunction with mechanical plowing. Chemicals usually are not stored at the heliport, but are acquired from a local airport when needed.

4) Many of the heliport operators surveyed do not have any future plans to install a pavement heating system. However, these operators had not forecasted future operational demands of the heliport.

5) Of the heliports that have pavement heating systems, many were installed to satisfy the need for the expedient and safe utilization of the helipad. In such cases cost may not be a consideration since safety is such a high priority.

6) Pavement heating systems are more practicable economically in terms of increased IFR helicopter operations. The establishment of 25 IFR equipped urban heliports by the year 2000 is a specific goal of the FAA's Rotorcraft Master Plan. The availability of these heliports and the burgeoning trend toward IFR helicopters implies that more consideration should be given to automated snow and ice removal.

7) Before IFR equipped helicopters can take advantage of the increased utility of VFR/IFR heliports during winter IMC (i.e., freezing rain and snow) the helicopters must also be certified for flight into know icing conditions. A near term goal of the FAA's Rotorcraft Program Office is to streamline the civil helicopter icing certification process.

The results of the engineering study provided the foundation for these additional conclusions:

8) Mechanical methods of snow and ice removal are viable anywhere in the U.S. where the annual snow load is greater than 5 lbs/ft^2. Below this level, snowfall and icing events are usually infrequent enough to allow natural melt-off. Mechanical or chemical methods can be used for locations below this level if demand dictates.

9) Mechanical methods are usually more practicable than mechanical/chemical or pavement heating systems in regions where the average winter temperature drops below 15°F.

10) Mechanical/chemical application is usually more practicable for regions where the annual snow load is greater than 5 lbs/ft^2 and the average winter temperature is greater than 15°F.

11) Pavement heating systems are more viable, in terms of annual operating cost, within regions having annual snow loads greater than 5 lbs/ft^2 and average winter temperatures greater than 15°F. In terms of operating efficiency, pavement heating systems designed for thermal flux between 100 and 300 W/m^2 are more suitable.

12) In terms of acquisition costs for the various snow and ice removal techniques, the mechanical method has the least expensive acquisition cost and solar is the most expensive.

13) As for annual operating and owning costs, the mechanical approach is typically the least expensive and solar is the most expensive, in terms of dollars. In regard to time costs, the mechanical approach requires one to two hours per snowfall event, and the pavement heating systems essentially have no time cost if the design is capable of melting the snow as it falls.

14) The boiler pavement heating systems appear to be the most cost effective technique of the pavement heating systems. However, where electricity is very inexpensive, such as Seattle, Washington, the electric heating method may be more cost effective.

2.0 SNOW AND ICE CONTROL - GENERAL CONSIDERATIONS

There are many innovative snow removal and ice control techniques being developed and tested, some of which have been successfully operational for several years. However, the proven manual approach, employing brooms, shovels and small plows is, by far, the most common solution for the heliport today. This is understandable in today's VFR helicopter environment. The average heliport in the U.S. has to cease operations only 3.6% of the time during the winter because of snowfall or icing conditions. While this percentage can range from 0.3% of the time to 9.5% of the time, the amount of time the operations are curtailed remains small in all cases. However, in the future, as IFR helicopters and helicopters certified for flight into icing conditions become more common, and as the number of scheduled operators at heliports increases, the demand for the new control techniques will increase.

In general, there are three considerations involved with selecting a method for removing snow and ice from a helipad: Safety, Increased Operations, and Cost. These considerations are largely site dependent, based upon winter storm activity, the types of helicopters, the type of operators, the frequency of operations, hours of operation, and type of helipad (ground level or elevated). These three considerations are discussed in the following sections in order to assist the heliport operator, designer,and/or planner in characterizing their heliport snow and ice control needs.

2.1 GENERAL CONSIDERATIONS

Expedience and Safety

The primary justification for installing a pavement heating system is to increase the percentage of time the helipad is available for operations while, at the same time, ensuring a high degree of safety. The main safety problem is ice. Rotor downwash can cause preferential icing on the pad and lead to dangerous, slippery working conditions very suddenly.

Heliports with pavement heating systems are more commonly found at private heliports, such as hospitals and large corporate offices with frequent daily helicopter operations. As for hospitals, the immediate concern is with the expeditious transportation of patients, thus requiring that the helipad be clear of snow and ice as much as possible for immediate access. Safe ingress and egress of fast moving personnel on the ground must also be ensured.

The corporate heliport is also interested in maintaining nearly continuous operations with a large margin of safety. Many corporations justify the large capital expense of the helicopter based on its high availability and fast point-to-point transport times. Such corporations do not want their helicopter operations restricted because of snow or ice build up on a helipad. Its safety requirements, as well, are in regard to the safe ingress and egress of passengers and crew.

This is not to imply that unheated helipads are less safe than heated helipads under all conditions. Only during periods of snowfall and/or icing conditions, which are hard to identify in advance 100% of the time, does the heated helipad have a safety advantage. In other words, an unheated helipad is equally safe but not as available as a heated pad.

Another consideration is what is termed "white-out", developed by snow hurled by rotor downwash which obscures pilot vision. Therefore, snow must be removed that accumulates in this region. The area affected is dependent on the largest helicopter the heliport is designed to service. In a general sense, an area approximately 3.5 times the rotor diameter size is normally sufficient to ensure that wake velocities have satisfactorily diminished to less than velocities induced in the plane of the rotor. This substantiated by reference 8 thru flow field measurements of a hovering rotor near the ground. Photographs of the flow fields indicate that for rotor diameter heights of 1 diameter, ½ diameter, and ¼ diameter, recirculation of smoke from the ground back up to the rotor did not occur above rotor heights of ½ diameter. When recirculation did occur, it was directly beneath the rotor hub with vary little if any recirculation beyond the rotor tips. Velocity measurements for rotor heights of ½ and ¼ diameters at various distances from the rotor hub, and heights above the ground demonstrate that wake velocities are largest close to the ground (heights of less than 0.1 times rotor radius). These velocities diminished rapidly for greater heights above the ground as the distance from the rotor hub increased. At a distance of 1.7 diameters from the rotor hub, and a rotor height of ½ diameter, the mean wake velocity was equal to the velocity induced in the plane of the rotor. At the same distance, for a rotor height of ¼ diameter the wake velocity reduced from 2.0 times the induced velocity beneath the rotor to approximately 0.8 times the induced velocity. Therefore, for a 40 foot rotor diameter, at approximately 68 feet from the rotor hub wake velocities have significantly diminished. This distance equates to an overall area of about 3.5 times the rotor diameter or 136 feet. Buildings with snow accumulation within this area should be cleared if operations demonstrate snow recirculation caused by the disturbed flow field.

Increased Operations

It might be expected that having a heliport closed less often for manual snow removal would allow for more helicopter operations, and thus justify the expense of a pavement heating system. This is typically not the deciding factor for heliports servicing VFR helicopter operations. Large accumulations of snow on a heliport that may require several hours to remove, usually occur during IMC when conditions are not suitable for VFR helicopter flight. Also, helicopters do not operate in known icing conditions unless they are certified. (Only the Super Puma is currently certified for operation in known icing conditions). In addition, if the heliport does not service a frequent number of operations, then the occasional large snow accumulation can be easily managed by mechanical equipment and chemicals. Therefore, pavement heating systems are not the

preferred approach for VFR heliports, but are a very strong candidate for IFR heliports servicing, or planning to service, deicing-certified helicopters.

Ground Level vs Rooftop Operations

Current rooftop heliport operators report that snow removal is an easy matter for them. Most of the time snow blows off before they can shovel it off. This is due to the unobstructed airflow commonly present at elevated helipads. Icing is also reported to be much less of a problem on rooftop, and elevated rooftop, heliports for the same reason. The snow does not collect on the pad to melt and refreeze because of the wind action. In addition, any rain which falls is drained away immediately and cannot collect on the pad.

Cost

More thorough discussion of expenses incurred for particular snow removal and deicing techniques is provided in Section 3.0. As would be expected, the cost of manual (mechanical) snow removal is less expensive than for pavement heating systems. For all these techniques there are a number of indirect or associated costs that should be considered. These costs for mechanical and mechanical/chemical include not only that of labor, plow equipment and chemicals, but also a dry storage shelter, chemical dispersal equipment, and possibly, maintenance equipment. An alternative route is to subcontract portions or all of the snow removal activity to a neighboring business.

As for pavement deicing systems, the associated costs lie in the additional expense of preparing the landing pad and substructure. Careful preparation of the ground on which the helipad will be placed is necessary to ensure that the earth is very stable. This will prevent shifting or settling from inducing fatigue and cracking the pavement along with time in-pavement heat dispensing system (pipes, cables, etc..). This will require the addition of controlled fill and compaction beyond normal design standards.

In addition, the concrete pavement should be strengthened to reduce fatigue and thermal stress, and prolong life. This is accomplished through using concrete with a reduced slump and by adding air entraining agents to increase strength and durability. Adding a coat of sealer and curing paper will also add to the strength and durability of the concrete pavement. These preparations should be anticipated in the cost of installation.

One other important factor to consider is that of Airport Improvement Program funding (AIP). Under the FAA's AIP, a heliport may qualify for funding if it will be open for public use. One of the features of the program includes the funding of snow removal and deicing equipment. Therefore, if future demand necessitates a pavement heating system, its costs may be defrayed through AIP funding[5].

2.2 CLIMATOLOGICAL REPRESENTATION OF SNOW REMOVAL AND DEICING EQUIPMENT

Factors to be considered in evaluating the heliports need for snow removal equipment, chemicals, or a pavement heating system, include:

1) the incidence of snow
2) average depth of snow per storm
3) density of snow
4) icing conditions
5) volume of helicopter operations, and
6) types of helicopters being used.

These factors were used in developing the climatological descriptions of the various snow and ice control methods which follow.

The National Oceanic and Atmospheric Administration weather data indicates that communities receiving a mean annual snowfall of 15 inches or less, usually receive less than two inches of snowfall per storm. Communities with 15 inches or more annually, have an average snowfall accumulation of two to six inches per storm[1]. Illustrated in Figure 2.1 is the mean monthly total snowfall for selected locations in the contiguous United States. Average snowfall accumulation rates for other locations can be provided by contacting the National Oceanic and Atmospheric Administration (NOAA) for local climatological data.[3] This presentation of data provides an indication of total snowfall and the number of months in which it occurs. Similarly, Figure 2.2 shows the approximate dividing line for 5 lbs/ft^2 of mean annual snowfall as the lower contour. These figures may be useful in selection of various snow and ice control methods. In comparing inches of annual snowfall with annual snow loads in lb/ft^2, 15 inches of snow in the western continental U.S. closely correlates to 5 lb/ft^2. In the eastern U.S., however, 15 inches roughly correlates to 10 lb/ft^2, indicting a greater water content. The 5 lb/ft^2 annual snow load contour was selected to represent the lower demarcation line to account for potential freeze/thaw problems associated with snow and ice near the 45° F zone. These parameters are not intended to indicate at what snow depth an operator should clear the helipad, but to assist in selection of a snow control method. A heliport operator should clear the helipad whenever snow or ice accumulation prevents indication of heliport boundaries or markings, and helicopter operations are anticipated. Being near the 5 lb/ft^2 contour alerts the operator to the compounding consequences of allowing snow to melt naturally and then possibly refreezing, making subsequent removal more difficult.

Heliports receiving less than 5 lbs/ft^2 of annual snowfall per year are likely not to need equipment other than a snow shovel or broom to clear the helipad for visibility. Above 5 lbs/ft^2 of snowfall annually, a snow plow and/or shovel would be an alternative. Also, shown in Figure 2.3 is a 15°F demarcation line. Above the 15°F line, snow plowing is more attractive, in that, the freeze/thaw cycle is no longer present. This environment is condusive to dry powdery snow which is easily removed since no adhesive icing conditions are present.

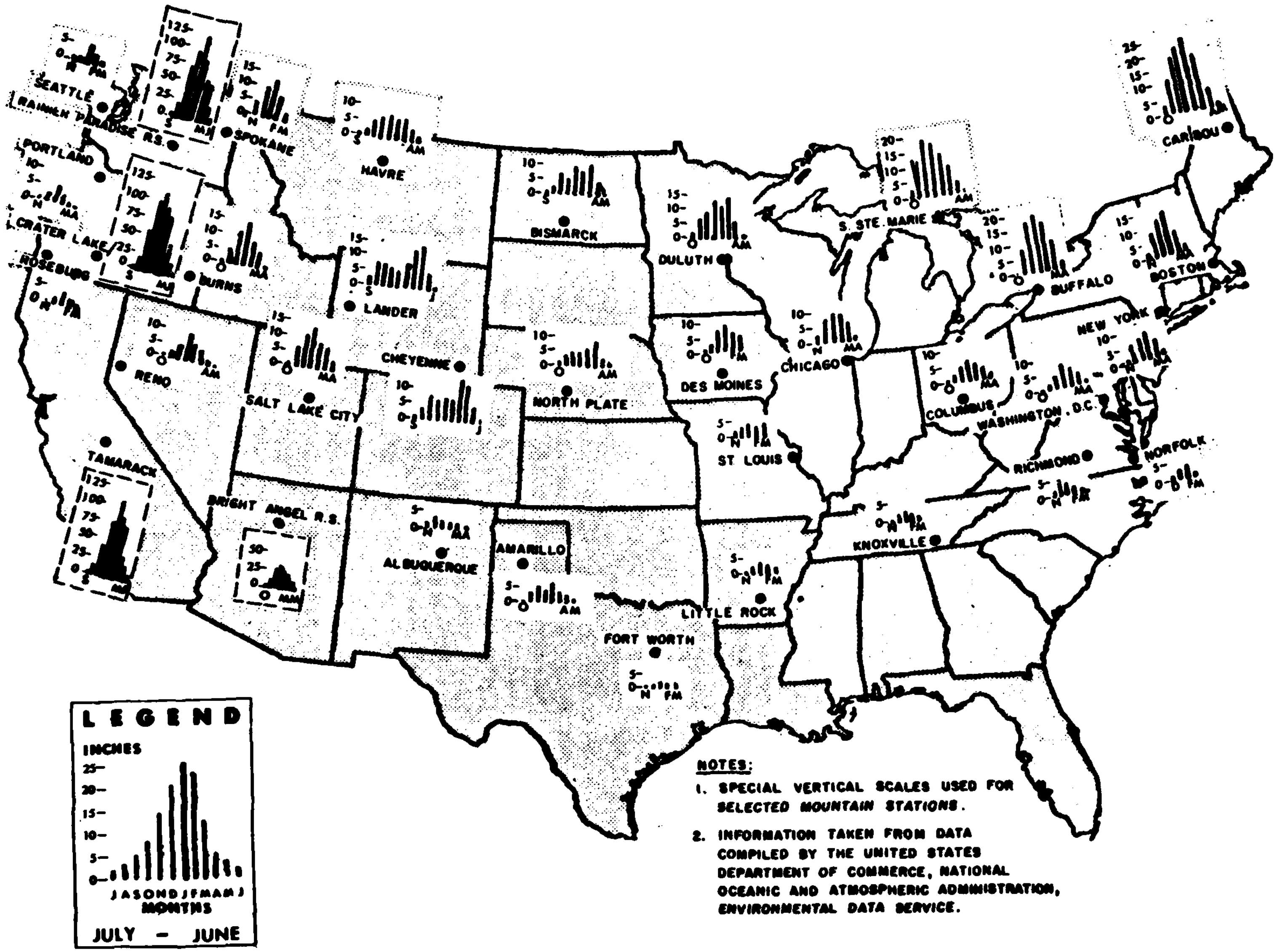
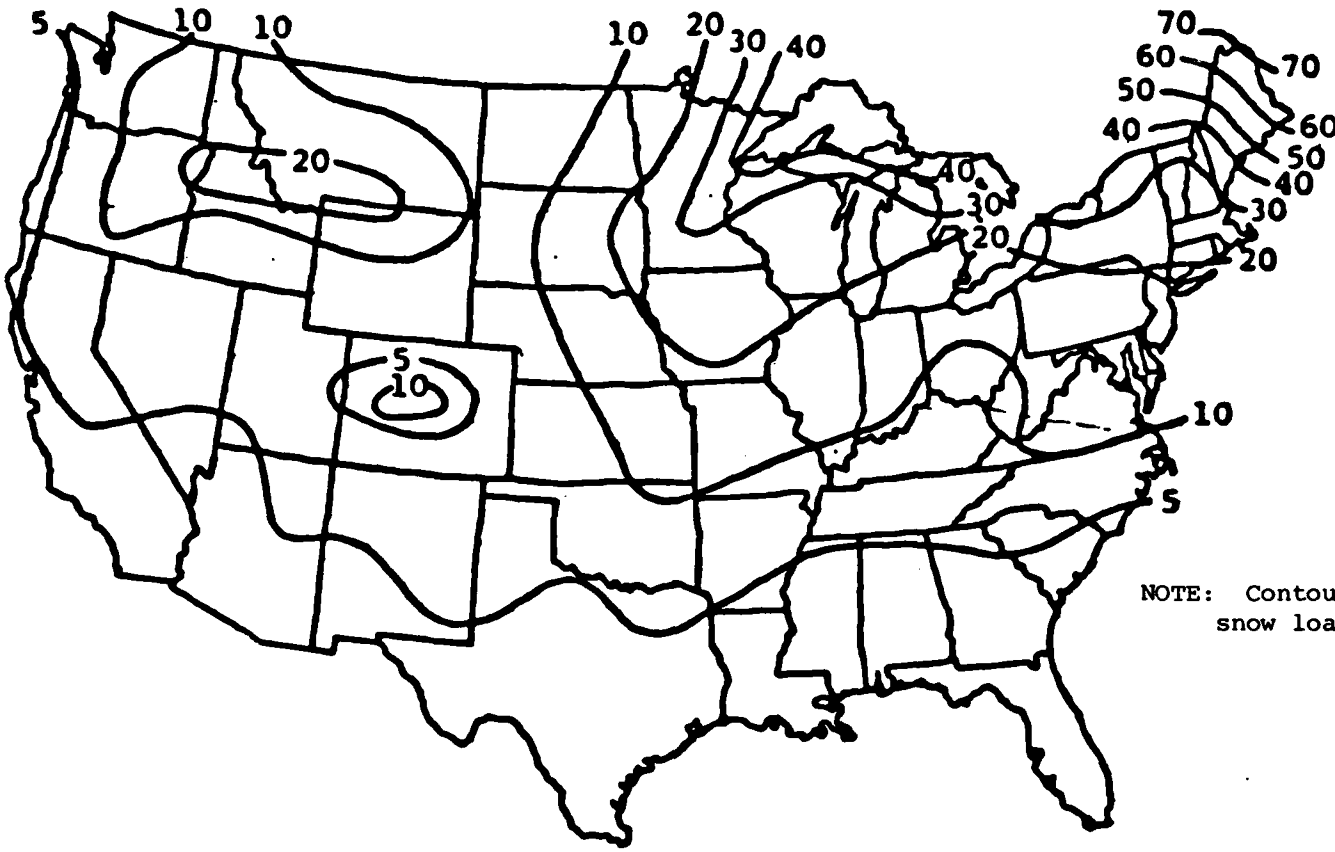


Figure 2.1 Mean Monthly Total Snowfall [1]



NOTE: Contours represent snow loads in lb/ft^2.

Figure 2.2 Snow Load in lb/ft^2 on the Ground, 0.04 Quantile, 25-year Mean Recurrence Interval

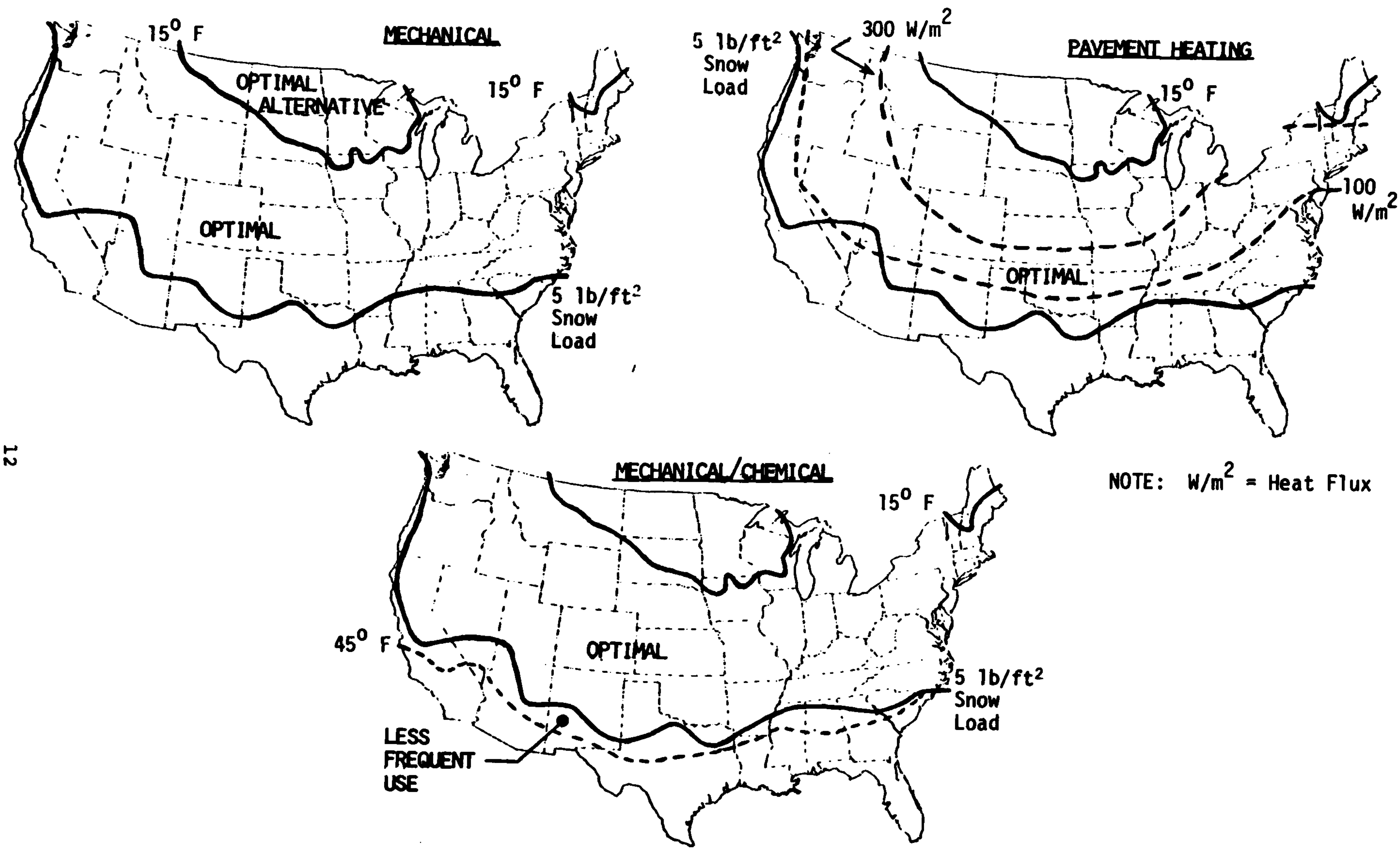


Figure 2.3 Climatological Representation of Snow and Ice Control Methods

The use of chemicals to augment mechanical snow and ice control is suited to many geographical locations. This is illustrated in Figure 2.3, for the contiguous U.S. The lower boundary, defined by the 5 lb/ft^2 and 45°F contour, demarcates weather data where freezing and thawing of precipitation can be expected. The upper contour indicates the 15°F mean winter zone. Between these two regions, both urea prills and liquid ethylene glycol are useful in breaking the ice to pavement bond. The region above the 15°F contour indicates the temperature at which urea prills are less effective in melting snow and ice. In this region ethylene glycol would be effective but perhaps not desirable. Because of the large volume of snowfall deposits in this region (5 to 10 inches per month) which accumulates due to the lack of a freeze/thaw cycle, chemical deicing could induce an unwanted freeze/thaw cycle. This would further hinder plowing activities.

The environment most suited to pavement heating systems is similar to that of mechanical, as shown in Figure 2.3. The lower solid contour represents the approximate dividing line for 5 lbs/ft^2 of mean annual snowfall. Below this line, deposits of less than two inches of snowfall per storm are the norm. Since storms below this line are much less frequent, snow and ice usually melts quickly or is easily removed mechanically. The upper contour line approximates the dividing line for 15°F, the area above which there is no longer a frequent freeze/thaw cycle.

Pavement heating systems operate at optimum where temperatures fluctuate about 32°F, although, they will operate at temperatures below 15°F, at greater energy costs. However, the volume of snowfall in the region above the 15°F line that would require melting is beyond the design limit of most pavement heating systems. An improper design could result in severe ice build-up on and around the helipad. Between these two contours, the thawing and repeated freezing of snow and ice during short time periods causes the greatest problem to heliport operations where immediate access is necessary. Since the environment fluctuates from above 32°F down to below 15°F, during most of the winter months, pavement heating systems can offer a viable means for maintaining an open heliport.

According to the chart, the more suitable area for pavement heating system application is further illustrated by the dashed contour lines in Figure 2.3. The upper dashed line indicates a general demarcation of 300 W/m^2 heat flux. These contours were developed from data for cities shown in the ASHRAE Guide[2]. Since so few cities were included in the ASHRAE Guide, these contours represent a rough approximation for optimal installations.

2.2.1 Icing Conditions on Heliports

The concern over icing is different for heliports and airport runways. On a runway ice and snow become compacted by aircraft. This adversely affects stopping distance and may also produce an occasion for turbine engine ice ingestion.

For heliports ice ingestion can also be a potential problem, but ice and snow compacted by rolling takeoffs and landings is out of the ordinary. A more necessary, and perhaps subtle reason for concern, other than safety or ground maneuvering, for public heliports, is to maintain adequate visibility of the helipad touchdown symbol and boundary.

Ice formed by the alternate melting and freezing of snow during the cold months of the year is much more frequent than icing conditions caused by freezing rain or sleet. Ice has the greatest possibility of formation when temperatures fluctuate about 32°F after less than one-half inch of snowfall. This level of snowfall, may not warrant removal if operations are done for the day, since it may appear to be melting. Icing conditions can occur with little or no warning during these periods of minor temperature fluctuations. Ice has also been observed to form on wet helipads when temperatures were slightly above 32°F, caused by a rotor wash, wind chill effect.

One other consideration is that of ground level and elevated helipads. Ground level helipads offer a thermal advantage over elevated in that the ground aids in reducing heat losses from the bottom of the pad. An elevated pad on a rooftop would exhibit greater thermal losses, since all sides may be exposed. If pavement heating is to be applied to a rooftop helipad, it is advisable that the pad have direct contact with the roof surface or have a significant amount of thermal insulation material added to the bottom and sides. Before going to the expense of heating an elevated pad, thoroughly investigate the characteristics of snowfall at the proposed site. It may be discovered that the snow will not adhere to the pad because of wind currents. In this event the only surfaces necessary for heating may be walkways.

It may also be possible to alleviate the need for heating many ground level helipads by applying the same approach. Using controlled fill, a helipad could be raised to a height, preferably above the mean annual snowfall depth. Except for the possibility of drifts on windward sides of the pad, the surface is likely to remain relatively clear. This approach would be more effective in the region north of the 15°F demarcation where snow accumulates rather than melts and refreezes (Figure 2.2). However, in the region described to be most suited for pavement heating systems, this approach could alleviate much of the snowfall that would adhere to the pad by blowing it off, thereby reducing the times of necessary operation.

In summary, heliport operators should ensure prompt removal of snow to prevent it from becoming ice formed by subsequent melting and freezing cycles. Icy surfaces present safety hazards to landing helicopters, passengers and crew. In addition, they can cause clogged drains, which can lead to worsening conditions.

The prudent heliport owner/operator should also evaluate the future demand of the heliport. Potential growth in helicopter operations and possible demand for IFR/IMC operations should be considered in planning a snow removal system.

3.0 SNOW AND ICE CONTROL TECHNIQUES

There are three techniques (mechanical, mechanical/chemical, and pavement heating) available to a heliport manager to keep a helipad clear of snow and ice. Each technique has advantages and disadvantages which must be evaluated against each heliports expected operations. A detailed analysis of each technique is contained in the following paragraphs, as well as guidelines for use of each technique.

3.1 GUIDELINES FOR USE OF MECHANICAL SNOW AND ICE CONTROL EQUIPMENT

Heliports are not as susceptible as airports to hazardous accumulations of snow and ice for a variety of reasons. Since a helicopter does not depend on ground friction for braking and directional control, a heliport need only keep the touchdown and maneuver areas clear. This is a job which most heliport operators will accomplish easily with shovels, brooms, 10 HP snow blowers, or a snow plow mounted on a pickup truck. This wide range of equipment is not all necessary for all heliports. There is a large difference between the needs of a rooftop heliport and a ground level heliport. The wind streaming across a rooftop helipad tends to keep the pad clear most of the time. In addition, rooftop pads are usually smaller than ground level helipads. Thus a rooftop helipad operator would probably require only shovels, brooms, and possibly a snow blower. On the other hand, a large ground level helipad might need a plow mounted on a pickup truck and a motorized broom.

In regard to truck mounted plows, the truck should be properly maintained, serviced, and operated by a skilled driver who is familiar with heliport equipment and operating rules and regulations. As noted previously in Section 2.3, ice is difficult to remove from pavements with a plow blade. Successful lifting of ice with a blade is dependent on having an initial crack or break at the pavement/ice interface [1]. Such a crack can be generated by using deicing chemicals, or an air hammer and blade if the ice is quite thick. Then the crack can be propagated using the snow plow. A 10° blade angle has been found to be the most efficient for removing ice. The velocity of the truck should be kept fairly high to continue crack propagation. The experienced plow operator should be able to judge the correct speed by observing the size of ice fragments generated. It is desirable to generate large ice fragments.

To prevent plow damage to helipad lighting fixtures, some heliports mark the fixture locations with brightly painted three foot by one inch wood dowels. The dowels should be removed prior to reopening the heliport for operation.

If the heliport is collocated at an airport, the airport will probably have sufficient snow removal capacity to handle the small additional load of clearing the heliport as well. Coordination with the airport to be included in their snow removal plan should then provide adequate snow protection. If large snow plows used for airport runways are to be used on the helipad, be sure that the wheel loading force of

these vehicles does not exceed the design strength of the pavement. It should be noted also that if the heliport is collocated with an airport having an air traffic control tower, all heliport vehicles including snow removal and ice control vehicles engaged in operations on the airplane movement areas should be equipped with a two-way radio. Radios should be operated on the appropriate ground control frequency.

If the heliport is on a rooftop, or elevated above a rooftop, there are special considerations to be recognized in regard to mechanical snow removal. There must be room on the roof to contain the snow to be removed from the pad. Also there must be a means of lifting the snow removal equipment up to the level of the pad. This will be of special concern to elevated pads. A snow blower may weigh in excess of 133 pounds and would be awkward for one man to lift up stairs. Storage facilities for both equipment and chemicals may also be considered based on the volume of annual snowfall. It should be noted that current rooftop helipad operators are experiencing little, if any, problems with ice forming on the pad.

The main advantage of mechanical snow and/or ice removal is its low cost. Most heliport operators will already have a suitable vehicle which can be adapted to plowing in the winter. Thus there are little or no acquisition costs for equipment which can be utilized only one third of the year. The only costs attributable to this technique are the cost of the plow, the operators wages, and the fuel for the vehicle. The main disadvantages of plowing include:

1) during plowing the heliport must be shut down
2) plowing is ineffective against sheet ice and may even damage the pavement

If the heliport has a low number of helicopter operations per day, then closing for plowing may not be a disadvantage. Also, the effectivness of plows against ice can be greatly increased by using deicing chemicals.

3.1.1 <u>Cost of Mechanical Snow Removal</u>

Mechanical snow removal is the most economical in terms of dollars, but the most expensive in terms of heliport down time. A 40 foot square ground level helipad in Boston, Massachusetts will incur costs of approximately $420-$525 per year removing snow with a plow mounted on a 1-1/4 ton truck. A 40 foot square rooftop helipad will incur costs of approximately $222 per year removing snow with a shovel and a small snow blower. The $525 figure per ground level helipads assumes the truck to be a necessary maintenance vehicle utilized all year. Therefore, the cost of owning the truck is not reflected in the $525 cost. However, the cost of the plow attachment, labor, and gasoline are included in this cost analysis. An average of 16 snowfalls of one inch or more per year are assumed based on NOAA local climatological data. The purchase price of the plow has been amortized over 3 years, as shown in Table 3.1. This results in costs of $525 per year for the first three years. Since the purchase price of the plow is small (approximately $260), the owner should evaluate whether or not it is worthwhile amortizing this cost.

Another cost associated with plowing is heliport down time. When a plow is used to clear the pad the heliport must shut down until plowing is finished. Depending on the depth and density of the snow this could take from one to several hours.

Table 3.1 Annual Cost of Ground Level Mechanical Snow Removal - Boston

OPERATING COSTS:			
LABOR:	(16 snowfalls/yr) x (2 man-hours/snowfall) x ($10/man-hour)	=	$320
FUEL:	(16 snowfalls/yr) x (1 vehicle hours/snowfall) x (5 gal/vehicle hr) x ($1.20/gal)	=	$100
			$420 per year
OWNING COST*:			$105 per year
TOTAL:			$525 per year

*$260 purchase price amortized over 3 years at 13% interest

The $222 figure for rooftop helipads assumes that a small snow blower and a snow shovel will be used to remove all snow accumulations. The $450 cost of the snow blower is amortized over three years as shown in Table 3.2. Labor rates are calculated based on the assumption that only one-half of the 16 annual snowfalls of one inch or more will require removal. Note that the cost of mechanical removal for rooftop helipads is approximately one-half of ground level operators.

Table 3.2 Annual Cost of Rooftop Mechanical Snow Removal - Boston

OPERATING COSTS:			
LABOR:	(16 snowfalls per yr) x (0.5 of snowfalls require removal) x (0.5 man-hours/snowfall) x ($10/man-hour)	=	$40 per year
OWNING COSTS:*		=	$182 per year
TOTAL:			$222 per year

*$450 purchase price amortized over 3 years at 13% interest

3.2 GUIDELINES FOR USE OF CHEMICALS TO AUGMENT MECHANICAL METHODS

Anti/deicing chemicals suitable for heliport application can be obtained as a solid, in pellet form, or as a liquid. Both types are

composed of materials which are noncorrosive to metals commonly used in aviation such as aluminum and magnesium. Care should be taken to avoid substitute chemicals not specifically recommended for aviation use.

Depending on the type of chemical agent chosen (solid or liquid), either a granular spreading device or a fluid distribution device may be employed. It is preferrable to employ these chemicals in an anti-icing mode, before the ice forms. However, caution must be exercised. Under certain conditions the use of these chemicals can result in the paved surface becoming very slippery by virtue of their own peculiar characteristics. High concentrations of both solid and liquid chemicals will result in slippery pavement conditions in their own right. For this reason, and because of environmental concerns, chemical agents should not be utilized to melt snow as it falls. Nor should the manufacturer's recommended application rate be exceeded. If ice has already formed, then depending on the concentration of chemical used, the chemical will melt the ice and result in a mixture of ice, slush, and water. This water, in combination with any ice which may remain could cause very slippery conditions. Therefore, prior to use of chemicals in a deicing mode, establish a test area to determine the results which will be obtained from the chosen concentration.

During the application of liquid chemicals, it is advisable to avoid physical contact with the chemicals or inhaling the fumes. Timing of chemical applications for ice control (particularly for anti-icing) may be made more effective by the use of remote surface condition monitoring equipment. These devices remotely transmit information on actual pavement surface temperature and moisture content to the heliport operations room. This allows operations personnel to anticipate helipad icing conditions and apply chemicals prior to ice formation when they are the most effective. Site specific factors may dictate the number of sensors installed. Among the installation facts are: helipad length and gradient, temperature, water and wind patterns. For more detailed information of pad surface condition monitoring equipment see Reference 6.

Urea (aero)[1] prills is urea especially formulated for use on airfield pavements and will have a greater concentration of soluable urea than the prilled urea used for agriculture fertilizer, but both are acceptable for use on airfield pavements for ice control. Urea should never be used when the surface temperature is below plus 15 degrees Fahrenheit as there will be absolutely no physical reaction, thus, no melting. Check manufacturer's specifications to determine the effective range of their specific product. Some of the liquid products have operating temperatures well below +15°F. These liquids are typically composed of liquid urea and ethylene gylcol, however, it should be noted that icing is not much of a problem below +15°F because the thaw/freeze cycle is normally not present.

Currently, most heliports prefer to use prilled, or granular, urea. The granular spreading devices may vary in size from a hand-pushed yard fertilizer spreader to large truck-mounted hoper-spreaders. The relatively small size of heliports makes the yard fertilizer spreader well suited for their needs. One man could probably cover the whole helipad in a short time with the hand-pushed spreader. In addition, the

urea prills are easier to see than liquids and insure a more even application rate. The rate of application suggested for urea (aero) prills is in the range of 0.32 to 2.17 pounds per square yard, contingent upon the surface temperature and the thickness of the ice, as shown in Table 3.3. It is suggested that a test area be used to predetermine the exact rate of application needed to produce the desired results.

Table 3.3 Typical Urea Application Rates [1]

	Ice-Dissolving Capacity of Urea in lbs per sq. yd. at Various Ambient Temperatures			
Ice Thickness	15°F	20°F	25°F	30°F
1/16 inch	1.09	0.79	0.50	0.16
1/8 inch	2.17	1.59	1.01	0.32
3/16 inch	3.26	2.38	1.51	0.48
1/4 inch	4.35	4.17	2.01	0.64
5/16 inch	5.44	4.96	2.52	0.80

In the future, however, liquids may become more prevalent. The small size of the helipad makes mechanical/chemical snow and ice control economically feasible. If operators wish to use chemicals at temperatures below +15°F a liquid must be used. Whenever chemicals are used to remove ice already formed, the previous comments on slush and water should be kept in mind. The water, on top of the ice, causes the condition to become worse. Passenger walkways and helicopter touchdown areas should be reopened only after a thorough inspection indicates the ice has been completely removed.

Urea prills should be stored in a dry location until ready for use as it requires adequate protection from moist or humid conditions during lengthy storage to prevent excessive caking and loss of material into solution. Urea is noncorrosive to aircraft and has no detrimental effect on airfield pavements[1]. Liquid chemicals can be purchased in bulk or in 55 gallon drums. The manufacturer should furnish a list of all the corrosion tests that the specific product has passed. One of the most notable characteristics of chemical anti-icing is the residual effect it exhibits which appears to inhibit the runway surface against subsequent bonding of ice or compacted snow for 2 to 3 days after each application. However, it should also be noted that excessive use of ethylene glycol based liquid chemicals beyond manufacturers recommendations on Portland cement concrete containing air entraining chemicals may significantly increase the concrete's rate of deterioration[9].

To gain the maximum benefit from urea, it should be applied only after the paved surface is well wetted either from falling snow or freezing rain and definitely prior to the formation of 1/8 inch of ice. Using urea in this anti-icing mode will allow the prilled urea to dissolve and a much smaller amount of urea will be needed to prevent the formation of the

ice-to-surface bond, thus, making any further ice accumulation easily removable by mechanical means. The rate of application under these conditions will be as given in the chart for 1/8 inch of ice thickness and appropriate to the existing surface temperature[1].

To gain the maximum benefit from liquid chemicals, it should be applied in accordance with the manufacturer's directions. These directions may vary from manufacturer to manufacturer. Many factors must be considered, such as air and ground temperature, humidity, wind speed and direction, and so on. No more than 3 inches of compacted snow or ice should be deiced. The liquid should be the same temperature as the ambient air. The application rate should be constant and uniform from the applicator and the applicator should be low to the ground in order to minimize wind dispersal. In addition, when anti-icing, the pavement should be free of any accumulations of fuel or soot which, in combination with liquid chemicals, might produce slippery and hazardous areas.

The main disadvantage of mechanical/chemical ice removal is that the heliport must cease operations during the time that the chemicals are applied and the ice mechanically removed. Operators will have to assess individually whether this is acceptable or not. Also, during a heavy snow or freezing rain situation the chemical may not be able to keep the pavement free of accumulations of ice. See Tables 3.3 and 3.4 for typical application rates. The advantages, however, are also significant. Chemicals are highly effective in facilitating mechanical methods. There are no high acquisition costs and no annual fuel costs incurred. Annual costs associated with chemical application will depend on the number of times chemicals must be applied to the surface.

3.2.1 Cost of Chemical Augmentation to Mechanical Ice Control

The cost of chemicals used as an anti-ice/deice agent will vary from one climatologic region to the next. The main considerations affecting the decision on whether or not to apply chemicals are:

1) how wet is the surface, and
2) is the temperature likely to go below freezing and cause icing.

Regions in the southern United States will not have many occasions when they have to worry about a wet pad freezing. Regions in the extreme northern United States will normally receive dry snowfall that clears easily and does not wet the pad. However, many operators in the mid and northern United States will have to be concerned about frequent freeze/thaw cycles, and many want to consider using chemical anti-icing. Heliport operators will have to assess their individual needs. For a 40 foot square helipad in Boston, Massachusetts will incur operating costs of approximately $125 dollars per year using chemical augmentation. Table 3.5 gives a break down of the operating costs involved with the use of chemicals.

Table 3.4 Typical Liquid Application Ratios

DEICING	Application Ratio at Indicated Air Temperature, gal/sq ft		
Depth of Packed Snow and Ice, inches	20° to 32°F		10° to
20°F	Less than 10°F		
2 to 3	1/250	1/200	1/100
1 to 2	1/500	1/200	1/150
1/2 to 1	1/750	1/500	1/300
Less than 1/2	1/1000	1/750	1/500

ANTI-ICING	
Runway Condition	Application Ratio, gal/sq ft
Expectation of general sub-freezing precipitation or icing conditions	1/3000
Expectation of freezing rain	1/2000

Table 3.5 Annual Cost of Chemical Snow Removal - Boston

OPERATING COSTS:			
LABOR:	(11 applications/yr) X (0.5 man-hour/application) x ($10/man-hour)	=	$55.
CHEMICALS:	($4/gal) x (gal/1000 ft) x (1600 ft) x (11 applications/yr)	=	$70.
OWNING COST:	Purchase price of spreader	=	$20. to $60
TOTAL COST:		=	$125*

*Total cost does not include purchase price of spreader.

3.3 PAVEMENT HEATING SYSTEMS

A pavement heating system consists of three separate subsystems:

1) a heat source system to provide heat energy
2) a heat transport system to transfer energy from the heat source to the distribution system, and
3) a heat distribution system to dissipate heat energy in the pad

There are many possible combinations of the three subsystems that will result in a viable pavement heating system. Which combination will be the most cost effective for a particular geographic location depends on many factors. A civil engineer who has experience with the planner's particular area will be the most qualified to design a pavement heating system. In addition, Sections 4.0 and 5.0 are useful in assisting the planner and/or designer in selecting the most appropriate system to meet the heliports demands.

Heat Source Subsystem

The heat source is the most variable subsystem. Almost anything that produces heat or has a temperature higher than the freezing point of water can be used as a heat source. For example, electricity, steam boilers of all types (oil, gas, coal), solar collectors, hot water heaters, geothermal energy, and air to liquid heat exchangers are all viable heat sources. In addition, because of the relatively low temperature at which the pad must be maintained to prevent freezing, other sources of heat are also available, such as earth heat. The temperature of the earth below the frost line approximates the average yearly temperature of the ambient air. If this deep earth (approximately 30 to 50 feet down) temperature is sufficiently above freezing, the energy stored in the earth can be used as a heat source. The same is true for ground water, which, if it can be found in enough quantity and at a high enough temperature, makes an excellent heat source.

Heat Transport Subsystem

The heat transportation subsystem has fewer variations. This subsystem transfers energy from the heat source to the heat distribution subsystem. When pipes are used, well insulated plastic or steel are common. Electric cables and pipes, both steam and liquid, cover almost all applications.

Heat Distribution Subsystem

Heat distribution subsystems can be divided into three categories:

1) electric heat cables or electric heat mats
2) heat pipes
3) EPDM (ethylene-propylene-diene-monomer) heat mats, fluid pipes, or steam pipes

A more detailed discussion of each type of distribution system can be found later in Section 3.3.1 through 3.3.3. However, before moving into the specifics of each system, a few more general design characteristics of pavement heating systems will be covered.

General Characteristics

To prevent over-design (too many heating elements and the accompanying extra expense) or under-design (too few heating elements and concomitant inability to melt snow or ice loads), the thermal flux of the proposed helipad must be analyzed. The required surface heat flux will vary with climatic conditions. Average winter temperature, winds, humidity, ground temperature, cloud cover, average snowfall in inches, and other factors must all be analysed to determine the number of watts per square foot a pavement heating system must be able to deliver. This task should be performed by the engineer who designs the pavement heating system, and has access to thermal flux tables for cities throughout the U.S.[2]

Besides the acquisition costs of the pavement heating system a heliport operator can also expect to pay more for the concrete that the system is set in. Extreme care must be exercised to prevent the concrete from cracking due to settling or thermal stress. It is necessary to pay special attention to the preparation of the subbase and base beneath the concrete to prevent settling. Thermal rods may be necessary to prevent cracks due to thermal stress. It is normal procedure to use concrete with a reduced sump and to add air entraining agents to increase the strength and durability of the concrete. In addition, the use a coat of sealer/hardener right after troweling and the application of curing paper will increase the strength of the finished pad. This preparation of the concrete is necessary to ensure that the installed system has a long life time over which to recoup the costs of installing the pavement heating system.

Drainage is another important consideration when installing a pavement heating system. Care must be taken to ensure there is no build-up of ice in unheated locations down grade from the heating system. All run-off from the heated portion of the pad must be drained. In addition, it may be necessary to heat the drains themselves to prevent them from freezing.

Another consideration is the possible advantage of installing insulation beneath the heated portion of the pad. This will lower the amount of heat lost into the ground.

A pavement monitoring system[6] is a consideration for the efficient use of pavement heating systems where the pad temperature is controllable. Pavement monitoring systems automatically control the pavement heating system and turn it on before the onset of freezing conditions. Usually a heating system will be controlled so as to "idle" or keep the pad just above 32°F most of the time. Then, if the pad is wet, the system will be turned up to a "melting" mode and will continue at this higher level of heat input until the pad is dry.

A pavement heating system involves a large investment which can be utilized only a fraction of the year. As was described previously in Section 2.1, there are two arguments justifying this expense: increased winter capacity; and increased safety for passengers and crew. Safety and expedience seems to be the driving factor on most of the pavement heating systems installed to date. Hospitals and executive transport operators are especially sensitive to this issue. The heating systems are installed beneath passenger walkways as well as beneath the touchdown area to prevent preferential icing of the pad by the rotor downwash on days when the pad is wet.

Heating systems keep the pad clear of snow build up in a storm. This should allow a helipad to handle more traffic since it does not have to close down in order to clear the pad. However, if the heliport will be closed due to poor visibility during a snow storm in addition to the accumulation of snow on the pad, there may not be an economic advantage to having a deicing system unless the heliport is open to IFR operations, such as on an airport. In the future, IFR heliports may be able to benefit from a clear pad during extended periods of snowfall during IMC.

Maintenance requirements will vary depending on the type of pavement heating system selected. The system designer or manufacturer should provide a maintenance guide which covers all required maintenance operations and a schedule of when the maintenance needs to be done.

Determination as to whether other locations would need to be concerned over snow and ice accumulation, and selection of a snow and ice removal methodology, should begin first with consideration of Figure 2.3. This figure will aid in identifying the relative degree to which a particular location is vulnerable to snow and ice accumulation. Secondly, Sections 4.0 and 5.0 will assist in the selection of a removal method relative to the climatological conditions of the desired location.

For the purposes of this study, design layouts have been developed for the climatological conditions of Boston, Massachusetts, and a pad 40 feet by 40 feet in size. This size was selected to accommodate helicopters with a rotor diameter of 40 feet or less. These helicopters represent 88.3% of the current active fleet. In actual application there are dimensions, other than rotor diameter, that may be planned for deicing, including rotor downwash area, maneuver area and walkways.

With any pavement heating system the cost in dollars is high compared to mechanical or chemical removal. However, the payback in terms of time saved and increased safety must be considered. With pavement heating systems the pad will remain clear in all but the most severe weather conditions, or approximately 98.3% off all snow storms. At a hospital, or other life saving operation, nearly 100% availability will be a high priority and may take precedence over the high yearly cost. Also, there will be less danger of a passenger or crewman slipping on isolated spots of ice with a pavement heating system. Certain operations may find this additional safety factor a high priority. These are advantages that mechanical and chemical snow removal cannot deliver. Each heliport must

analyze its particular operation to decide whether it can justify the additional cost of the pavement heating system. There is also the possibility of qualified public use heliports obtaining AIP funding to defray the cost further.

3.3.1 Electrical Pavement Heating System

An electrical system will consist of voltage transformers, a control room, high voltage underground cables, a pavement surface condition indicator, electric heating cables or mats, and a drainage system. A typical layout for an electrical pavement heating system is shown in Figure 3.1. The required ratings for the transformers, high voltage cables, and heating cables will depend on how much power the system is required to deliver.

The required power ratings can be obtained from the ASHRAE[2] Systems Handbook or by using local weather information obtained from NOAA.

The electric system has the advantage of having fixed acquisition costs per unit area. Since electricity is the heat source, there is no expense for a heat source, such as a boiler or solar panels, unless a transformer is necessary. Another advantage is that electric systems require very little maintenance. On the other hand, electricity is an expensive form of energy and may have higher operating costs than any of the other systems.

There are also two disadvantages of electric heating cables that must be considered. The heating cables are subject to failure at the point where the cable enters the pavement and anywhere a crack in the pavement occurs. Water can seep into the heating cables at these points and cause shorts. Also, if the pavement settles and cracks, the heating cables can be broken. Therefore, great care must be taken in preparing the base for the slab (see Section 3.3).

3.3.1.1 Cost of Electric Pavement Heating System

As shown in Table 3.6, electric pavement heating systems are expensive to operate in comparison with mechanical or chemical snow removal methods. Electric heating is also more expensive than using an oil fired boiler system. However, this estimate is based on electric rate of $0.08 per KW-HR and $0.0625 per KW demand charge for Boston, Massachusetts, as shown in Table 3.7. These rates are relatively high when compared to other areas of the country. Lower electric rates may make the electric system more attractive. For this presentation, fully 79% of the yearly cost of the system are attributable to the electric bill (operating cost/owning cost).

Table 3.6 Annual Operating Costs of Snow Removal Systems - Boston

METHOD:	MECHANICAL	MECHANICAL/ CHEMICAL	PAVEMENT HEATING				
			ELECTRIC	LIQUID PIPE			HEAT PIPE
				Boiler	Solar/ Boiler	Solar	Earth Heat/ Boiler
$/YR:	$420-525	$650	$5318	$2913	$5046	$7673	$3332
Time/ Event	1-2 hr	1-2 hr	0	0	0	0	0

Table 3.7 Annual Cost of Electric Pavement Heating System - Boston

OPERATING COSTS:			
Electricity:	(base rate): ($0.08/KW-HR) (demand charge): ($0.0625/KW-HR)	=	$4027
OWNING COST:	(Financing $9,187 over 20 years at 13% interest) (12 months) ($107.63/ per month)		$1,291 per year
TOTAL:			$5,318 per year

1) Electricity costs based on 32,720 KW-HR per year delivered to a 40 foot square pad by Boston Edison Company (general service rate G-1) as specified in 1980 ASHRAE Systems Handbook.[2]

The owning costs of the electric pavement heating system are $1,291 per year. This figure is arrived at by amortizing the $9,187 purchase price over 20 years. Table 3.8 provides a breakdown of the purchase price of the electric pavement heating system, based on manufacturer's specifications.

Table 3.8 Acquisition Costs of Electrical Pavement Heating System

Heating Cables*	$6267
Controller	$1000
Installation**	$1920
TOTAL	$9187

*Based on Manufacturer's Design Specifications

**(4 man-hours/100 ft^2 x (1600 ft^2)
x ($30/man-hour) = $1920

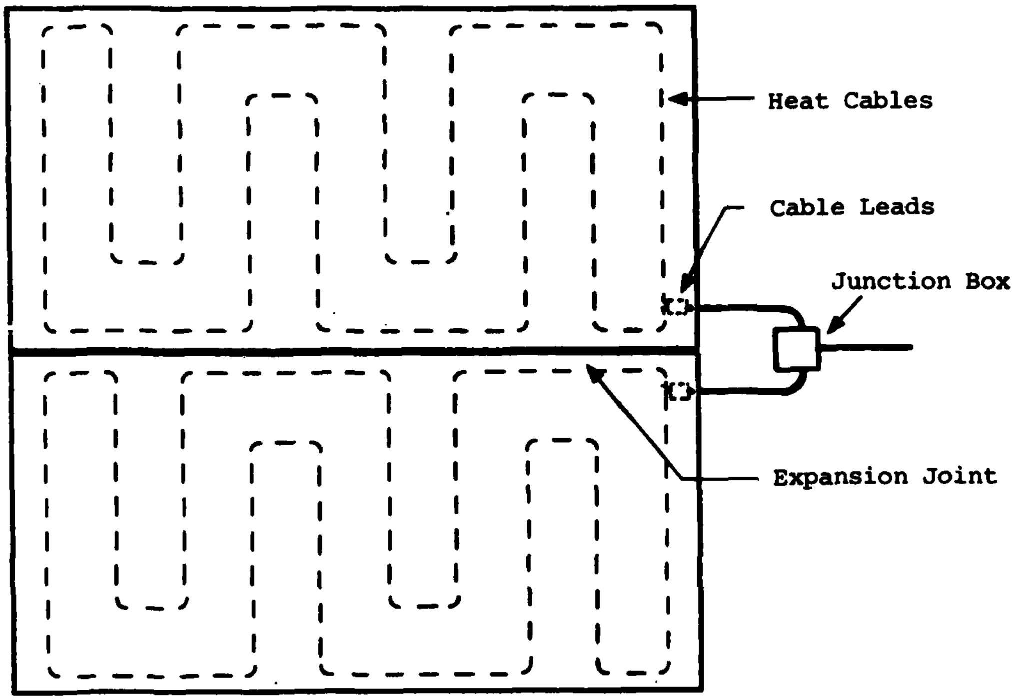


Figure 3.1 Electrical Pavement Heating System

3.3.2 Fluid Pipes and Mats

A fluid pipe system will consist of a heat source, expansion tank, control values, an optional pavement surface condition indicator, fluid storage tanks, pumps, a fluid which will not freeze in the pipes, and an area drain. A typical layout for a fluid pipe (or mat) system is shown in Figure 3.2. The amount of power required can be obtained from the ASHRAE Systems Handbook[2] or by using local weather information.

Fluid mats are made of EPDM plastic and are flexible enough to resist breakage from shifting within the concrete. Fluid pipes do not have this advantage. Both are based on proven technologies and are simple to install using off the shelf parts. Since the heated fluid is pumped through the pipes there is not a problem of ensuring that the pipes have an adequate slope as there is with heat pipes.

3.3.2.1 Cost of Liquid Pipe (or mat) Systems

As shown in Table 3.6, liquid pipe or liquid mat systems are expensive to operate in comparison with mechanical snow removal methods. The costs of three different heat sources, boiler, solar with boiler augmentation, and solar, for the liquid mat system, are presented in Table 3.9. The boiler system has the lowest owning costs, $1342 per year, and the highest operating costs $1571 per year. The solar system has the highest owning costs, $7323 per year and the lowest operating costs, $350 per year. The acquisition cost (Table 3.10) of the solar system $52,088 is significantly higher however, and probably not a viable alternative with today's solar technology. This is based on the fact that the life of solar systems are essentially the same as other pavement heating systems. As a result, it is not normally possible to obtain extended periods of amortization over 20 years. Even a 30 year amortization only reduces the yearly owning by $409 or 6%. Therefore a third system, solar with boiler augmentation, was designed in order to gain the benefits of both systems. A hybrid boiler/solar system does not need the large storage capacity, or as many solar collectors, as a pure solar system. This results in an acquisition cost savings of $38,541. In addition, the fuel costs of the hybrid system are lower because the sun is providing 30% of the heat flux needed to supply the system. Individual operators should perform a life cycle analysis of the costs of each system in order to select the most appropriate system.

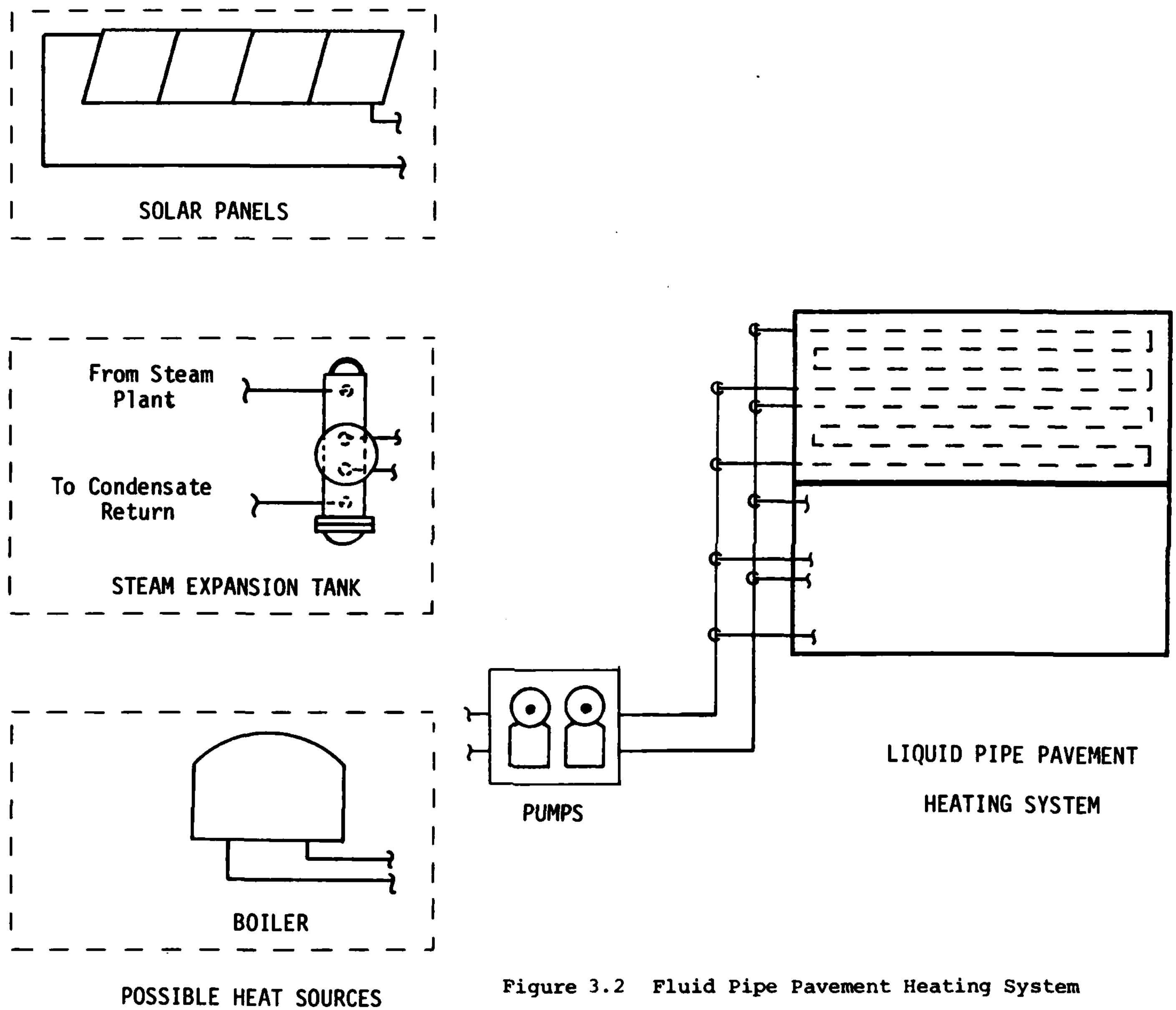


Figure 3.2 Fluid Pipe Pavement Heating System

Table 3.9 Annual Cost of Liquid Pipe (or Mat) Systems - Boston

SYSTEM:	BOILER	SOLAR WITH BOILER AUGMENTATION	SOLAR
OPERATING COSTS: (per yr)			
FUEL*	$1271	$ 887	0
MAINTENANCE:	300	350	$350
SUBTOTAL	$1571	$1237	$350
OWNING COSTS:**(per yr)	$1342	$3141	$7323
TOTAL:	$2913	$5046	$7673

* Fuel costs calculated based on 109.6 million BTU/year delivered to pad as specified in 1980 ASHRAE Systems Handbook.[2]

** See Table 3.10 for acquisition cost of system, then amortize purchase price over 20 years.

Table 3.10 Acquisition Cost of Liquid Pipe (or Mat) Systems - Boston

SYSTEM:	BOILER	SOLAR/BOILER	SOLAR
BOILER	$2700	$ 994	$ 0
SOLAR COLLECTORS	0	5120	10240
PUMPS	(included with boiler)	260	260
MATS & PIPES	6848	6848	6848
STORAGE TANKS	0	325	25000
TOTAL	$9548	$13547	$52088

3.3.3 Heat Pipe Distribution Systems

A heat pipe is a device that transfers large amounts of heat energy from an area of high temperature to an area of low temperature. It can be thought of as a "thermal diode" since it allows heat to be conducted in only one direction. The operation of a heat pipe is fairly simple. It consists of two sections of pipe, an evaporator and a condenser which are connected together and filled with a working fluid, as illustrated in Figure 3.3. This working fluid must be two phase, liquid and vapor, at the temperatures the heat pipe is expected to operate. The evaporator is lower than the condenser and in contact with a heat source. This vaporizes the working fluid and causes it to rise up into the condenser section. Here the working fluid condenses back into a liquid, which releases the latent heat of vaporization. The liquid now flows back down into the evaporator due to gravity, and the whole process starts again.

Heat pipes have many advantages when applied to pavement heating systems. They are made of steel or iron and are thus resistant to small movements in the pavement. Also, there are no mechanical or electrical parts, so a heat pipe should last for many years without maintenance. Since heat pipes utilize latent heat they are isothermal in operation. This means that the heat will be transferred preferentially to the coldest section of the condenser tube. In other words, the heat is transferred to where it is needed most. And finally, the last advantage of heat pipes is their ability to use low-grade energy sources such as earth heat and ground water. The disadvantage of heat pipes is their relatively high acquisition cost. However, this is offset somewhat by the lower annual operating costs such a system will have.

3.3.3.1 Heat Pipe Pavement Heating System

A heat pipe system will consist of a heat source, heat pipes, control valves, and a drainage subsystem. If the system is to have an active mode in addition to the normal idle mode, a pavement surface condition indicator will be necessary as well. Many heat sources may be used to drive this system. The most advantageous heat source will vary with each application depending on the severity of the winter climate and the availability of heat sources for other purposes. However, if "waste" heat from any source is available in sufficient quantity it will probably prove to be the most economical. For example, boiler return pipes and ground water might be used as a heat source for heat pipes.

A major advantage of this application is that a passive heat source, such as ground water or earth heat can be used to keep the system idling. By design, the idling mode should keep the helipad clear approximately 50% of the time. Then, during periods of severe snowfall or icing an active heat source can be utilized to supply the system with enough thermal energy to maintain a clear pad.

3.3.3.2 Cost of Heat Pipe Pavement Heating System

As shown in Table 3.6, a heat pipe pavement heating system, driven by heat extracted from ground water and from a boiler, is slightly more expensive to operate than a 100% boiler/liquid pipe pavement heating system. However, this estimate was based on climatological conditions for Boston, Massachusetts, which are marginal for supporting an earth heat dependent system. As pads further south are considered, the temperature of the ground water will increase and more heat will be available to heat the pad. This may eliminate the need for boiler augmentation, which will reduce the cost of the heat pipe system even further.

Additional savings are also possible if a source of waste heat is available. Heat pipes can draw their energy from return lines to a steam boiler, sewage lines, or almost any source of heat. When considering the use of waste heat, however, the designer should consider the cost of reheating the returned fluid if a closed system is to be the heat source.

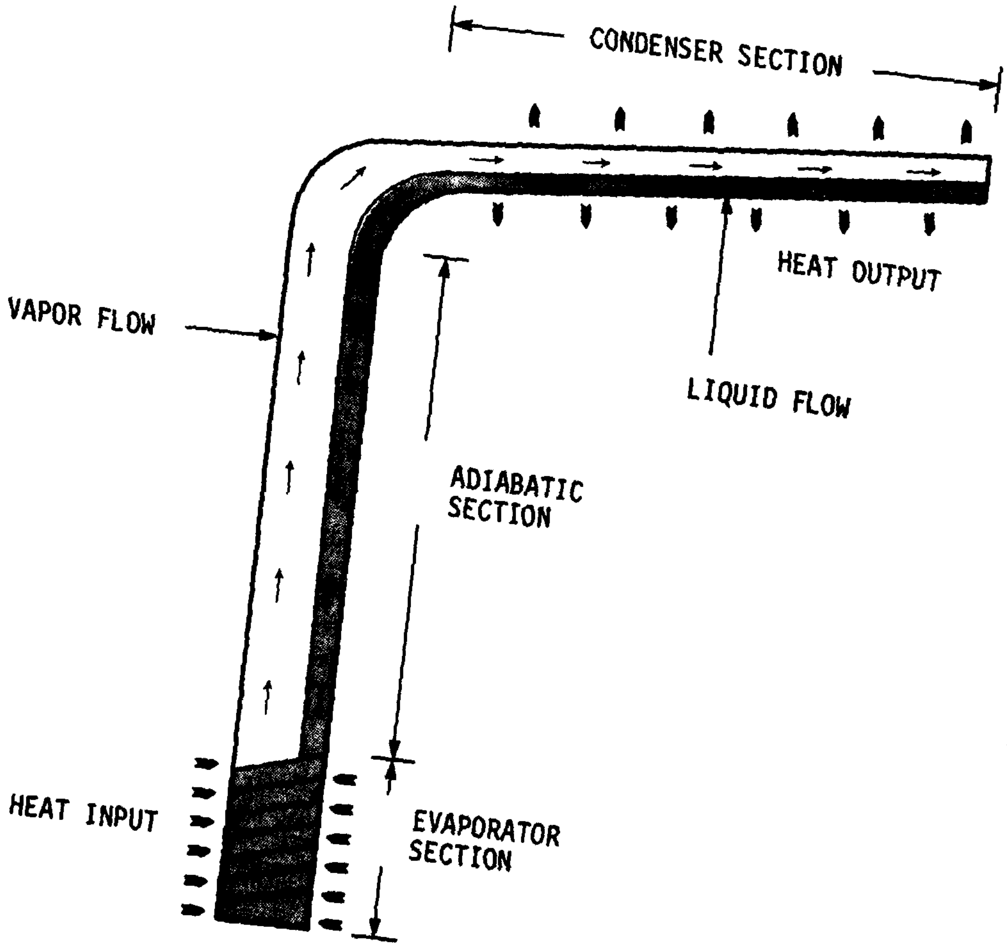


Figure 3.3 Schematic Illustration of a Heat Pipe

The owning costs of the heat pipe pavement heating system are $2516 per year. This figure is arrived at by amortizing the $17,900 purchase price over 20 years (Table 3.12). Table 3.11 provides a breakdown of the yearly operating costs of a heat pipe pavement heating system, based on manufacturer's specifications. The total annual owning and operating cost amounts to $3332. Although this cost is comparable to the boiler system, the heat pipe with boiler augmentation system may prove to be less expensive annually for cities with high fuel costs. This is due to the boiler system being more dependent on fuel for energy and therefore, more sensitive to fuel pricing.

Table 3.11 Annual Cost of Heat Pipe Pavement Heating System - Boston

OPERATING COSTS		
	FUEL	$171.96
	ELECTRICITY	343.89
	MAINTENANCE	300.00
SUBTOTAL		$815.85
OWNING COSTS:		$2516.52
TOTAL:		$3332.37

Table 3.12 Acquisition Costs of Heat Pipe Pavement Heating System*

Heat Pipes, Manifolds, and Installation:	$12,800.
Boiler, Control System, and Installation:	4,100.
2 Wells, 50 Feet Deep:	1,000.
TOTAL:	$17,900.

*Based on manufacturer's design specifications.

4.0 BENEFIT/COST DECISION GUIDELINES

Performing a cost/benefit analysis is necessary to rationally select the most appropriate snow removal and ice control system as a function of the cost of heliport operations.

Since most heliports' costs and profits are unique to the type of operations it caters, it is difficult to express numerically a quantifiable benefit representing the norm of heliports. However, it is possible to identify specific items that reflect potential benefits to a heliport. With such a list, the heliport owner or planner can selectively choose those benefit types that represent the heliport's loses due to snow and ice. Having accomplished this, the next step requires dividing the total annual benefits by the annual operating costs of various snow removal and deicing systems to arrive at a benefit/cost ratio. The systems having ratios greater than or equal to one, indicate a payback of the system costs. The process for calculating a benefit/cost ratio are described in the following sections.

4.1 HELIPORT OPERATIONS BENEFITS

The intent in quantifying the annual benefits of heliport operations is to justify the expenditure associated with particular snow removal and deicing systems. Therefore it is desirable to determine the annual dollar value lost due to the heliport being closed during and subsequent to snowfall and/or icing conditions. To the extent that the heliport can remain open during these conditions represents deicing system benefits.

There are a number of factors that affect the realization of deicing system benefits. The most important and obvious one is the type of helicopter, secondary is the frequency of helicopter operations. Heliports with scheduled service may experience greater revenue losses than heliports having infrequent operations that may be delayed. Taking this point one step further, heliports having IFR operations may be more cost sensitive to delays caused by snow and ice accumulation, due to the large accompanying cost of IFR equipment at the heliport.

In order to take advantage of the heliport, both present and future, it is important to consider forecasts of VFR and IFR operations at the heliport. This can be accomplished through assistance from the FAA Regional Office, surveying the current operator's future plans, or performing a market analysis.

The cost considerations regarding the value lost due to heliport down-time are listed in Table 4.1. This list is not meant to be all inclusive, nor does it imply that each heliport has at least these cost aspects. It is also quite possible that cost considerations other than those in Table 4.1 will apply and should therefore be considered in the total yearly benefits lost calculation.

Table 4.1 Annual Heliport Down-Time Cost Considerations

1.	VFR Operations	6.	Parking Fees
2.	IFR Operations	7.	Restaurant Revenue
3.	Fuel Sales	8.	FBO Revenue
4.	Landing Fees	9.	Schedule Carrier Revenue
5.	Tie-Down Fees	10.	Maintenance Revenue

In the attempt to justify a large initial expense, it is probably appropriate to calculate the annual down-time cost for three to five years projections. This will allow determination of the year in which the benefit to cost ratio is greater than or equal to one.

4.2 SYSTEM COST DECISION TABLE

The impetus for developing a cost decision table is to allow the heliport planner or designer to easily select the most cost effective snow and ice control system in relation to geographic location and type of operation. At the very least, this approach will allow a narrowing of the possible alternatives. The principal usefulness of using the cost decision table is as a planning or decision making tool and not as a design tool, since the costs are based on particular design assumptions and parameterized over a number of cities. As a result, the best estimate benefit/cost analysis may be slightly different than calculations based on actual site specific engineering plans.

The heliport planner or designer may forego use of the cost decision table approach in order to obtain more precise ratios, by requesting design cost proposals from various designers or manufacturers of pavement heating systems. However, this will be at the expense of time and convenience.

As mentioned previously, the operating cost decision table is based on certain design assumptions. One assumption is that a typical helipad is approximately 40 feet square. It is recognized that the annual operating and owning cost of a 40 foot square helipad cannot be linearly extrapolated to other pads of greater or lesser dimensions, although the magnitude of the change will be nearly proportional to the change in operating and owning costs. One possible approach that was planned was to perform a parametric evaluation of operating cost for helipads other than 40 foot square, but was postponed due to lack of time during the contract performance period. This approach requires calculating operating cost for a range of helipad sizes, for each deicing method, and for a number of selected cities (i.e., cities provided in the ASHRAE Guide). Performing a regression analysis of this data may indicate a measure of data continuity allowing the development of costs applicable to most or all cities for each helipad size. Helipad operating costs as a function

of helipad size could then be calculated and normalized such that the 40 foot square pad heating system and city of Table 4.2, and dividing by the desired size scaling factor for the same snow and ice control system would provide a size adjusted operating cost.

Since these size factors were not developed, performing the benefit/cost calculation explained in the following paragraphs, will provide a reasonable ratio for pad sizes 30 to 50 foot square.

Another assumption in regard to the operating costs of Table 4.2, is that the material requirements and thus the acquisition and owning costs for other cities would be favorably comparable to those of Boston. Annual operating costs for electric pavement heating systems are based on electrical rates per Typical Electric Bills - January 1, 1983.[7]

It should also be pointed out that annual operating costs of Table 4.2 are provided only for those cities listed in the ASHRAE 1980 Systems Handbook, Chapter 38[2]. If the city desired is not listed in Table 4.2, select the nearest city to the desired location. Also note that mechanical/chemical and earth heat operating costs are calculated only for Boston. No values are given for the other cities in Table 4.2 because of the wide variations which will exist for individual operators. The equations for estimating these operating costs are given in Appendix B. This resulted from the variability of conditions for mechanical/chemical, such as freeze-thaw cycles, rainfall frequency and the water content of the snow. Earth heat presented similar problems, such as ground temperature, the severity of the winter climate, and the availability of other heat sources.

The method for calculation of the benefit to cost ratio is straightforward, as illustrated in equation 1. Simply select an annual operating cost (AOC) from Table 4.2 for the nearest city and corresponding deicing method. Determine the annual benefit lost (HDT), as described in Section 4.1, and divide by AOC.

$$HDT/AOC = BCR \qquad \text{Equation 1}$$

where:

AOC = Annual Operating Cost from Table 4.2
HDT = Annual Value of Heliport Down-Time due to Snow and Ice (Section 4.1)
BCR = Benefit/Cost Ratio

The resultant figure is the benefit/cost ratio, either representing break-even (equal to 1.0), an annual operating loss (less than 1.0), or an annual operating profit or system payback (greater than 1.0).

These steps can be applied to any number of deicing systems and even over a range of years, provided annual operating benefits are projected over successive years.

Clearly, the prudent heliport owner or planner will request a design and cost proposal from an engineer or manufacturer for the pavement heating system selected. Based on these site specific cost designs, the heliport planner can more accurately estimate the annual operating and owning cost, and thereby project in what year, system payback can be expected.

Table 4.2 Annual Operating and Owning Cost

CITY	ST.	MECHANICAL	MECHANICAL/ CHEMICAL	ELECTRIC	BOILER	SOLAR/BOILER	EARTH HEAT/ BOILER
Albuquerque	NM	$210		$2563	$2204	$3884	
Amarillo	TX	289		3565	2589	4152	
Boston	MA	525	$650*	5318	2913	4379	$3332*
Buffalo-Niagra Falls	NY	1024		6380	3504	4790	
Burlington	VT	840		7224	4721	5640	
Caribou-Limestone	ME	1076		12285	6483	6870	
Cheyenne	WY	709		5787	4624	5573	
Chicago	IL	551		8357	4128	5226	
Colorado-Springs	CO	473		3546	3642	4887	
Columbus	OH	499		4335	2896	4367	
Detroit	MI	604		5824	3401	4719	
Duluth	MN	814		14348	8546	8310	
Great Falls	MT	735		6548	5470	6163	
Hartford	CT	578		5359	2941	4398	
Lincoln	NB	420		5504	4177	5261	
Memphis	TN	263		1799	1926	3690	
Minneapolis-St. Paul	MN	604		9263	6518	6895	
Mt. Home	ID	866		2968	2874	4351	
New York	NY	446		8480	3171	4559	
Ogden	UT	683		5293	3149	4543	
Oklahoma City	OK	236		2922	2492	4085	
Philadelphia	PA	394		2971	2177	3865	
Pittsburg	PA	656		5343	3175	4562	
Portland	OR	368		1445	1739	3559	
Rapid City	SD	525		8573	4894	5761	
Reno	NV	420		4556	2733	4253	
St. Louis	MO	394		3257	2604	4163	
Salina	KS	263		4056	3111	4517	
Sault Ste. Marie	MI	1313		11739	5696	6320	
Seattle-Tacoma	WA	446		1393	1793	3597	
Spokane	WA	709		3468	3034	4463	
Washington	DC	$341		$2498	$2110	$3818	

*The costs in this column are greatly influenced by the operator's requirements and climate. See Appendix B for equations to calculate expected costs.

5.0 SELECTION GUIDELINES

In the event that the heliport planner has difficulty in selecting the most appropriate snow and ice control system, this section will provide guidance. It is assumed that Section 2.2 and 4.0 have been reviewed. These sections, respectively, identify climatological aspects of various systems.

The selection guidelines prompt evaluation of a number of factors to lead to a choice between mechanical, mechanical/chemical, or pavement heating systems. They do not provide for specific delineation between pavement heating systems. If this alternative is recommended by the guidelines, cost comparisons, as described in Section 4.0, will narrow down the selection.

The guideline decisions are based on determinant factors such as, safety, climatology, IFR operations, and time and dollar budgets. These determinant factors, or decision points, are organized in such a manner to lead the planner to a logical choice. This process is illustrated in Figure 5.1. Every possible contingency cannot be specified in Figure 5.1 without over complicating the flowchart. Therefore, the flowchart may appear to be limited at certain junctions. The following discussion of the process will provide the needed flexibility to the guidelines.

The process begins by determining the heliport safety requirements. Every heliport experiencing snow and ice will operate with certain safety considerations. These considerations will relate to the manner and extent to which snow and ice are to be removed. Some heliports may desire to have the entire heliport pad and facility cleared, while others may clear only the takeoff and landing area and walkways. The manner in which snow and ice are removed can also lead to further safety considerations. If a heliport uses mechanical or mechanical/chemical snow removal methods, then only authorized personnel should be allowed in the vicinity of the activity. For the application of chemicals, treated areas should be inspected for slipperiness prior to opening for public access. These considerations are a function of how much of the heliport is open to personnel, crew, and passengers. As heliport operators and planners actively pursue methods of increasing public and personnel safety, insurance liability premiums may also reduce. However, this is dependent on the insurance companies being made aware of these activities so that data bases can be developed with the intent of justifying reduced liability cost as a function of activities and equipment used to alleviate icing accumulation.

Associated with the safety considerations and the manner in which the pad is cleared, is the amount of time available to physically clear the pad. Using mechanical means can consume one to three hours per snowfall event, depending on the amount of snowfall or ice accumulation. Pavement heating system operation for all practical purposes, does not result in any lost time, since it would be turned on or idling prior to inclement winter weather. Based on the type and frequency of operations at the heliport, the planner should determine acceptable time losses.

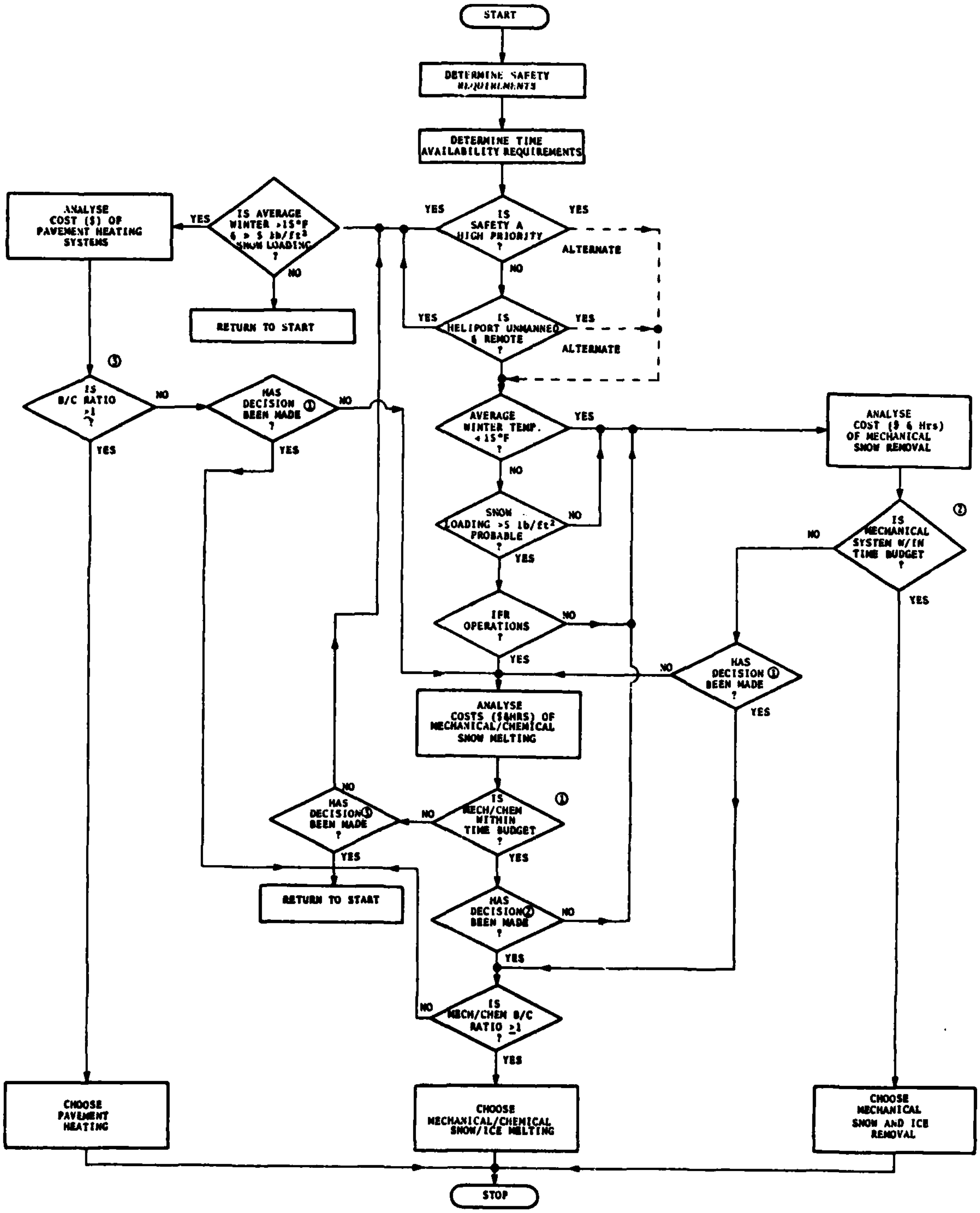


Figure 5.1 Flowchart of Deicing System Selection Guidelines

Following this evaluation, the next determinant factor relates to the level of priority attributed to heliport safety during icing conditions. This factor is, of course, a subjective evaluation as to what costs and efforts the planner will go to assure safety. When the facility is a public-use or a medical heliport, for example, safety is an important consideration. If cost is no object for the assurance of safety, then it certainly is a high priority. The flowchart implies that when safety is a high priority, the only choice is a pavement heating system. And conversely, if safety is not a high priority then the only choices include mechanical or chemical application. However, this is not true since a high degree of safety can be attained through mechanical and chemical means, and at a lesser cost. This is illustrated by the dashed "alternative" path in Figure 5.1.

The next determinant factor is whether the heliport is manned or unmanned. The flowchart implies that unmanned facilities should be equipped with pavement heating systems. However, this is not to say that services for clearing helipads manually cannot be contracted to local businesses or individuals.

Climatological data of the heliport location are the next factors or decision points. The guidelines at these junctions are based on pavement heating systems operating most economically at average winter temperatures greater than 15°F and where snow loads are greater than 5 lbs/ft^2. As always, it is the discretion of the owner to install a pavement heating system in other regions deemed necessary. Chemical application also works best for these same conditions. Mechanical snow and ice removal is applicable to these climates as well as for temperatures less than 15°F. More discussion has been provided on this subject in Section 2.2.

The decision factor for IFR operations is situated in the guidelines such that a heliport equipped for IFR will also probably be equipped with a pavement heating system. Although an IFR heliport could be relieved of snow and ice accumulation through mechanical and chemical techniques, it is probable that the level and type of traffic at the heliport will not justify the time losses associated with mechanical clearing. The possible alternative should not be ignored altogether, however. A time budget analysis using local climatological data of snowfall events, and projected IFR operations and schedules will assist in selecting a suitable snow and ice control approach.

One final determinant factor that should be discussed is the benefit/cost ratio. A thorough explanation of this subject was presented in Section 4.0. It is assumed that the heliport planner is familiar with this section and has identified and totaled the estimated benefits lost due to snow and ice accumulation. Once the planner has arrived at this decision point for the chemical approach or for pavement heating systems, determining the benefit/cost ratio will either eliminate a choice or produce a favorable ratio greater than or equal to one. However, as mentioned in Section 4.2, a ratio value less than one may still be a reasonable choice if subsequent yearly projections of the ratio do increase to 1.0 to greater. It should also be mentioned that there is no

benefit/cost ratio decision point for the flow-path leading to mechanical/chemical snow removal selection. This is because there are no other choices to consider for snow and ice removal, although, it would be a useful calibration of the heliports snow removal cost effectiveness.

These selection guidelines may appear too cumbersome and needless to some planners. However, heliports experiencing high operating costs, frequent IFR (or even special VFR) helicopter operations, and providing many services aimed at helicopter operators will probably realize the necessity of a methodical selection process. This is especially true if the proper selection may result in increased operations, greater heliport utility, and ultimately greater profits.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the results of a comprehensive engineering study and detailed telephone discussions with heliport operators, architects, and planners:

CONCLUSIONS:

1) The majority of the heliports in the U.S., located in regions having annual snowfall activity, do not presently have a sufficient number of helicopter operations to justify the expense of a pavement heating system

2) The most common method of snow and ice removal is mechanically, by means of shovels, brooms, and truck or small lawn tractor mounted plows.

3) Chemical application is not a common method for ice control. It is used in conjunction with mechanical plowing. Chemicals usually are not stored at the heliport, but are acquired from a local airport when needed.

4) Many of the heliport operators surveyed do not have any future plans to install a pavement heating system. Neither had operators forecasted future operational demands of the heliport.

5) Of the heliports that have pavement heating systems, many were installed to satisfy the need for the expedient and safe utilization of the helipad. In such cases cost may not be a consideration since safety is such a high priority.

6) Pavement heating systems are more practicable economically in terms of increased IFR helicopter operations. The establishment of 25 IFR equipped urban heliports by the year 2000 is a specific goal of the FAA's Rotorcraft Master Plan.

7) Before IFR equipped helicopters can take advantage of the increased utility of VFR/IFR heliports during winter IMC (i.e., freezing rain and snow), the helicopters must also be certified for flight into know icing conditions. A near term goal of the FAA's Rotorcraft Program Office is to streamline the civil helicopter icing certification process.

The results of the engineering study provided the foundation for these additional conclusions:

8) Mechanical methods of snow and ice removal are viable anywhere in the U.S. where the annual snow load is greater than 5 lbs/ft^2. Below this level, snowfall and icing events are usually infrequent enough to allow natural melt-off. Mechanical or chemical methods can be used for locations below this level if demand dictates.

9) Mechanical methods are usually more practical than mechanical/chemical or pavement heating systems in regions where the average winter temperature drops below 15°F.

10) Mechanical/chemical application is usually more practicable for regions where the annual snow load is greater than 5 lbs/ft^2 and the average winter temperature is greater than 15°F.

11) Pavement heating systems are more viable, in terms of annual operating cost, within regions having annual snow loads greater than 5 lbs/ft^2 and average winter temperatures greater than 15°F. In terms of operating efficiency, pavement heating systems designed for thermal flux between 100 and 300 W/m^2 are more suitable.

12) In terms of acquisition costs for the various snow and ice removal techniques, the mechanical method has the least expensive acquisition cost and solar is the most expensive.

13) As for annual operating and owning costs the mechanical approach is typically the least expensive and solar is the most expensive, in terms of dollars. In regard to time costs, the mechanical approach requires one to two hours per snowfall event, and the pavement heating systems essentially have no time cost if the design is capable of melting the snow as it falls.

14) The boiler pavement heating systems appear to be the most cost effective technique of the pavement heating systems. However, where electricity is very inexpensive, such as in Seattle, the electric heating method may be more cost effective.

15) The ASHRAE Systems Handbook[2] provides best estimate thermal flux data for only select 32 representative cities in the U.S. Since local climatological data may be significantly different for cities other than those in the handbook, the heliport planner/designer should consult the procedures described in the ASHRAE Systems Handbook or Appendix A of this design guide, or the state professional engineering society for thermal flux data that may have been calculated for the cities of interest.

RECOMMENDATIONS:

1) Provide tables of thermal flux data for as many cities as possible in the U.S. Climatological data evaluation will identify what cities can be grouped together as a means of consolidating the table. This centralized source of thermal flux data will allow for simplification of calculations and aid in evaluating alternative geographic locations for site selection.

2) To improve the cost decision factor estimates of Table 4.2, a table of scaling factors of operating cost for helipads other than 40 feet square should be developed. This will require performing the parametric evaluation of various helipad sizes, snow and ice removal systems, and ASHRAE cities described in Section 4.

3) Similarly, a parametric evaluation to develop acquisition cost scaling factors for helipads other than 40 foot square, will provide more accurate data on which to assist in selecting a pavement heating systems.

4) The Rotorcraft Program Office (RPO) of the FAA should actively pursue installation and evaluation of pavement heating systems at select national prototype heliports. The persuasion for this activity is the continued growth of IFR equipped helicopters and the concomitant development and growth of VFR/IFR heliports. If these heliports experience aborted helicopter operations due to snow and ice, then the heliports design utility is hampered.

5) The FAA's RPO should continue aggressive activities for streamlining the civil helicopter icing certification process. This is necessary to assure that the VFR/IFR heliport can be used during freezing IMC.

REFERENCES

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4. Anonymous: "Rotorcraft Master Plan"; Department of Transportation, Federal Aviation Administration, Associate Administrator for Aviation Standards, Rotorcraft Program Office; December 1983

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APPENDIX A

Methodology for Determining Heat Flux Data for Cities not in the ASHRAE Systems Handbook*

The equations used to calculate the heat flux of a helipad are taken from the 1980 ASHRAE Systems Handbook[2]. All equations are thoroughly explained in this reference. The equation used to determine heat flux for the application of a pavement heating system is:

$$q_o = q_s + q_m + q_e + q_h \tag{1}$$

where q_o = total slab heat output
q_s = sensible heat transferred to the snow to heat it to 32°F
q_m = heat of fusion (melting)
q_e = heat of evaporation
q_h = heat transfer by convection and radiation

In all cases q_x has the units BTU/h.ft^2

$$q_s = 2.6S\,(32-t_a) \tag{2}$$

where
S = average rate of snowfall in inches of water equivalent per hour
t_a = ambient air temperature

$$q_m = 746S \tag{3}$$

$$q_e = h_{fg}\,(0.0201v + 0.055)\,(0.185 - P_{av}) \tag{4}$$

where
h_{fg} = heat of evaporation at the waterfilm temperature in BTU/lb (from a table of the properties of saturated water)
P_{av} = vapor pressure of moist air in inches of mercury (from a psychrometric chart)
v = wind speed in mph

$$q_h = 11.4\,(0.0201v + 0.055)\,(33 - t_a) \tag{5}$$

The solution of equations ((1) through (5) requires the simultaneous consideration of four factors, (1) wind speed, (2) air temperature, (3) relative humidity, and (4) rate of snowfall. Thus a frequency analysis must be done for all occurrences of snowfall for several years and a chart like Table A.1[2] must be compiled. In other words, equation (1) must be solved independently for every time it snows over a period of several years. Data for this approach can be obtained by contacting the local weather bureau and requesting the actual data for the above four variables.

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*The equations and tables in Appendix A are reprinted with permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

However, Table A.2 shows an expedient, and less accurate, method for solving equation (1). Use the data from the local weather bureau to create a table of snowfall data over a ten year period as shown in Table A.2. Use the value for (S) that is obtained from Table A.2. Then use

	(t_a)	=	$0^{\circ}F$
and	(v)	=	15 mph to solve equation (1)

Caution must be used when applying this expedient method since the solution will not be as accurate and may result in an over-designed system.

Example:	S	=	0.16 inches of water/hr	h_{fg} $(32^{\circ}F)$ = 1075.4 Btu/lb
	t_a	=	$0^{\circ}F$	P_{av} $(32^{\circ}F)$ = 0.048 in Hg
	V_a	=	15 mph	relative humidity = 65%

then:	q_s	=	$(2.6)(0.16)(32-0) = 13.31$ Btu/hr.ft^2
	q_m	=	$(746)(0.16) = 119.36$ Btu/hr.ft^2
	q_e	=	$(1075.4)[(0.0201)(15) + 0.055]\ (0.185 - 0.048) = 52.5$ Btu/hr ft^2
	q_h	=	$11.4\ [(0.0201)\ (15) + 0.055]\ (33-0) = 134.12$ Btu/hr.ft^2
	q_o	=	$q_s + q_m + q_e + q_n = 319$ Btu/hr.ft^2

Here is one solution to equation (1). If Table A.2 was used to obtain (S), then the answer becomes the design output for the snow melting system. If, on the other hand, a more accurate design is required, the designer must repeat the equations for all of the snowfalls for several years and tabulate them as done in Table A.1.

Table A.1 Data for Determining Operating Characteristics of Snow Melting Systems[a,b]

City	Period of No Snowfall: Air Temperature[c]: Over 32 F (0°C), % of winter hours with no snow at above temperatures	Below or Equal to 32 F (0°C), % of winter hours with no snow at above temperatures	Mean during freezing period[g] F (°C)	Wind speed freezing period[g] mph (km/h)	Hours of Snowfall[c] %	Hours of Snowfall[c] Hour per year	Period of Snowfall[d]: Free area ratio, A_r	Required Output,[c] Btu/h·ft² (W/m²): 0 to 49 (0 to 156)	50 to 99 (157 to 313)	100 to 149 (314 to 471)	150 to 199 (472 to 629)	200 to 249 (630 to 787)	250 to 299 (788 to 944)	300 to 349 (946 to 1102)	350 to 399 (1103 to 1259)	400 up (1260 up)	Maximum Output Btu/h·ft² (W/m²)
								Frequency distribution of snowfall hours at above outputs, %[f]									
Albuquerque,	74.7	24.7	26.2	8.5	0.6	22	1	62.0	25.4	7.6	4.2	0.0	0.8	—	—	—	259 (817)
NM			(−3.3)	(13.7)			0	94.1	5.9	—	—	—	—	—	—	—	82 (259)
Amarillo,	73.1	26.0	24.6	13.3	0.9	33	1	33.7	35.4	15.4	10.7	3.0	1.8	—	—	—	260 (820)
TX			(−4.1)	(21.4)			0	88.1	10.1	1.8	—	—	—	—	—	—	143 (451)
Boston,	64.6	31.4	24.7	14.2	4.0	145	1	51.5	30.0	12.3	4.3	1.2	0.6	0.1	—	—	320 (1009)
MA			(−4.1)	(22.9)			0	83.2	14.0	2.0	0.3	0.3	0.1	—	0.2	—	370 (1167)*
Buffalo, NY Niagara Falls	46.5	46.9	23.9	10.8	6.6	240	1	50.7	32.6	11.2	3.7	1.4	0.2	0.2	—	—	309 (975)
			(−4.5)	(17.4)			0	95.9	3.4	0.2	0.5	—	—	—	—	—	192 (606
Burlington,	39.0	54.5	19.6	10.8	6.5	236	1	53.7	29.9	13.2	2.5	0.6	0.1	—	—	—	280 (883)
VT			(−6.9)	(17.4)			0	91.8	7.6	0.6	—	—	—	—	—	—	142 (448)
Caribou, ME; Limestone	21.4	70.6	16.5	10.0	8.0	290	1	35.0	39.7	16.0	5.7	2.0	1.0	0.5	0.1	—	378 (1192)
			(−8.6)	(16.1)			0	92.0	7.5	0.5	—	—	—	—	—	—	138 (435)
Cheyenne,	46.4	49.8	21.5	15.3	3.8	138	1	16.5	26.2	19.4	13.1	8.6	4.7	4.2	4.7	2.6	499 (1574)
WY			(−5.9)	(24.6)			0	94.3	5.4	0.3	—	—	—	—	—	—	129 (498)
Chicago,	45.4	50.9	21.4	11.5	3.7	134	1	45.8	37.4	11.4	3.1	1.4	0.6	0.2	0.1	—	368 (1161)
IL			(−5.9)	(18.5)			0	91.5	8.1	0.3	0.1	—	—	—	—	—	165 (520)
Col. Springs,	54.3	43.6	22.1	11.5	2.1	76	1	26.8	36.3	19.0	7.5	4.4	5.5	0.5	—	—	311 (981)
CO			(−5.5)	(18.5)			0	98.4	1.6	—	—	—	—	—	—	—	63 (199)
Columbus,	59.0	38.1	24.5	10.0	2.9	105	1	65.8	22.4	8.0	1.7	1.7	0.4	—	—	—	261 (823)
OH			(−4.2)	(16.1)			0	97.7	2.3	—	—	—	—	—	—	—	72 (227)
Detroit,	47.0	49.3	24.1	10.6	3.7	134	1	60.4	27.7	9.3	1.5	0.8	0.3	—	—	—	278 (877)
MI			(−4.4)	(17.1)			0	95.9	3.5	0.6	—	—	—	—	—	—	140 (442)
Duluth,	12.6	80.5	14.5	12.0	6.9	250	1	23.7	32.9	20.6	13.7	4.3	2.5	1.7	0.6	—	382 (1205)
MN			(−9.8)	(19.3)			0	94.8	4.7	0.0	0.3	0.2	—	—	—	—	206 (650)
Falmouth,	68.5	29.5	25.5	12.8	2.0	73	1	50.0	33.9	14.2	1.6	0.3	—	—	—	—	204 (643)
MA			(−3.6)	(20.6)			0	91.5	7.4	1.1	—	—	—	—	—	—	144 (454)
Great Falls,	49.0	46.2	16.5	14.4	4.8	174	1	26.2	27.6	16.7	16.4	7.5	4.6	0.3	0.5	0.2	451 (1422)
MT			(−8.6)	(23.2)			0	94.6	4.8	0.6	—	—	—	—	—	—	138 (435)
Hartford,	56.4	38.9	24.4	8.2	4.7	171	1	48.4	34.6	11.2	4.3	0.8	0.7	—	0.1	—	396 (1249)
CT			(−4.3)	(13.2)			0	80.4	16.7	2.2	0.5	—	0.1	—	0.1	—	383 (1208)
Lincoln,	45.0	52.5	20.8	10.1	2.5	91	1	32.7	26.2	20.0	13.9	5.7	1.5	—	—	—	293 (924)
NB			(−6.3)	(16.3)			0	97.2	2.6	0.0	0.0	0.2	—	—	—	—	202 (637)
Memphis,	87.2	12.5	27.0	11.5	0.3	11	1	48.4	28.3	6.7	13.3	3.3	—	—	—	—	227 (716)
TN			(−2.8)	(18.5)			0	85.0	8.3	6.7	—	—	—	—	—	—	144 (454)
Minneapolis, St. Paul, MN	23.6	70.8	16.9	11.1	5.6	203	1	28.4	31.4	21.7	14.1	3.5	0.6	0.3	—	—	313 (987)
			(−8.4)	(17.9)			0	96.5	3.1	0.3	0.1	—	—	—	—	—	155 (489)
Mt. Home,	56.3	42.6	24.9	9.5	1.1	40	1	74.2	21.9	3.9	—	—	—	—	—	—	143 (451)
ID			(−4.0)	(15.3)			0	98.1	1.9	—	—	—	—	—	—	—	90 (284)
New York	55.7	42.2	24.2	11.8	2.1	76	1	53.1	31.8	9.4	2.2	1.5	1.7	—	0.3	—	385 (1214)
NY			(−4.4)	(19.0)			0	87.6	9.6	1.5	0.7	0.3	0.3	—	—	—	298 (940)
Ogden,	50.0	45.6	24.3	9.4	4.4	160	1	64.6	29.2	5.8	0.3	0.1	—	—	—	—	216 (681)
UT			(−4.3)	(15.1)			0	88.8	9.4	1.4	0.3	0.1	—	—	—	—	216 (681)*
Oklahoma	79.0	19.8	24.6	15.8	1.2	44	1	27.8	18.7	17.0	12.6	14.3	5.9	2.7	1.0	—	394 (1243)
City, OK			(−4.1)	(25.4)			0	95.7	4.3	—	—	—	—	—	—	—	81 (255)
Philadelphia,	75.8	22.6	26.7	9.7	1.6	58	1	62.3	23.6	10.4	2.3	0.9	0.5	—	—	—	296 (934)
PA			(−3.0)	(15.6)			0	84.3	14.0	1.1	0.2	0.4	—	—	—	—	229 (722)
Pittsburgh,	55.2	39.8	24.3	11.6	5.0	182	1	53.6	30.8	8.4	4.6	1.9	0.7	—	—	—	282 (889)
PA			(−4.3)	(18.7)			0	93.3	5.9	0.7	0.1	—	—	—	—	—	157 (495)
Portland,	92.9	6.1	28.9	8.4	1.0	36	0	78.0	16.9	5.1	—	—	—	—	—	—	125 (394)
OR			(−1.8)	(13.5)			0	91.5	8.5	—	—	—	—	—	—	—	97 (306)
Rapid City,	45.2	51.6	19.3	12.9	3.2	116	1	29.7	29.0	16.0	8.4	6.3	3.6	1.9	2.0	3.1	581 (1832)
SD			(−7.1)	(20.8)			0	97.6	2.2	0.2	—	—	—	—	—	—	102 (322)
Reno,	56.0	41.6	24.3	5.6	2.4	87	1	82.6	15.4	1.8	0.2	—	—	—	—	—	152 (479)
NV			(−4.3)	(9.0)			0	90.2	8.0	1.6	0.2	—	—	—	—	—	154 (486)*
St. Louis,	68.7	30.4	25.0	11.5	0.9	33	1	42.9	31.4	16.7	7.1	1.9	—	—	—	—	225 (710)
MO			(−3.9)	(18.5)			0	85.2	11.6	2.6	0.6	—	—	—	—	—	152 (479)
Salina,	60.0	38.5	23.3	10.9	1.5	54	1	44.9	31.9	12.7	7.6	2.2	0.7	—	—	—	286 (902)
KS			(−4.9)	(17.5)			0	93.5	6.2	0.3	—	—	—	—	—	—	120 (378)
Sault Ste.	21.3	69.2	18.6	9.4	9.5	345	1	45.7	32.8	14.3	5.7	1.4	0.1	—	—	—	262 (826)
Marie, MI			(−7.5)	(15.1)			0	97.9	2.0	0.1	—	—	—	—	—	—	144 (454)
Seattle, WA; Tacoma	88.0	10.8	28.5	5.9	1.2	44	1	86.3	12.3	1.4	—	—	—	—	—	—	137 (432)
			(−2.0)	(9.5)			0	91.0	8.1	0.9	—	—	—	—	—	—	128 (404)
Spokane,	48.5	46.1	25.7	10.7	5.4	196	1	62.6	28.7	7.4	1.1	2.0	—	—	—	—	205 (647)
WA			(−3.5)	(17.2)			0	92.0	7.8	0.2	—	—	—	—	—	—	127 (401)
Washington,	77.9	21.2	26.8	9.6	0.9	33	1	59.0	29.8	10.6	0.6	—	—	—	—	—	154 (486)
DC			(−2.9)	(15.5)			0	85.7	11.8	2.5	—	—	—	—	—	—	121 (382)

Table A.2 Snowfall Data for Various Cities

City	Number of Readings with Maximum Temperature in 6-Hour Period Below Freezing at Various Snowfall Rates — Snowfall Rate in Equivalent Inches (mm) of Water per 6 Hour: 0.00 to 0.24 (0 to 6.3)	0.25 to 0.49 (6.35 to 12.5)	0.50 to 0.75 (12.6 to 19)	0.75 to 0.99 (19.1 to 25.1)	Total Readings Taken	Assumed Design Rate of Snowfall[b] S in./h (mm/h)
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Albany, NY	2052	29	5	1	3720	0.16 (4.1)
Asheville, NC	463	5	1	0	3536	0.08 (2.0)
Billings, MT	1640	4	0	0	3532	0.08 (2.0)
Bismarck, ND	2838	0	0	0	3720	0.08 (2.0)
Cincinnati, OH	1045	3	0	0	3720	0.08 (2.0)
Cleveland, OH	1569	2	0	0	3720	0.08 (2.0)
Evansville, IN	916	5	1	1	3720	0.08 (2.0)
Kansas City, MO	1189	12	2	1	3720	0.16 (4.1)
Madison, WI	2370	5	2	0	3720	0.08 (2.0)
Portland, ME	2054	33	4	1	3720	0.16 (2.0)

[a] Data from U.S. Weather Bureau. Based on readings taken 1:30 a.m., 7:30 a.m., 1:30 p.m., and 7:30 p.m. daily from November 15 to February 15 from 1940 to 1949. (Where the total readings are less than 3720 the period of record is less than 10 years). The difference between Col. 6 and the sum of readings in Cols. 2, 3, 4, and 5 is the number of readings with a maximum temperature (in the 6-h period) above freezing.

[b] The design rate is found as follows: Proceed to left (on line from any city) from Col. 5 until the column containing the tenth reading is found. Assume that the larger value in the heading of the selected column is an *average maximum* value, and should be multiplied by 2 to obtain the maximum rate for a 6-h period. This maximum rate divided by 6 is the design rate per hour. This is equivalent to dividing the larger value in the heading of the selected column by 3.

For example: For Albany, N.Y. Cols. 5 and 4 total six readings, and consequently the tenth reading is in Col. 3, which has the larger value of 0.49 (12.5) in the column heading. Dividing 0.49 (12.5) by 3, the design water equivalent of 0.16 in. (4.1 mm) per hour is found, as listed in Col. 7.

APPENDIX B

Methodology for Determining Operating Costs for Mechanical/Chemical and Earth Heat/Boiler Snow Removal Techniques

The equation used to calculate the annual operating cost of mechanical snow removal with chemical augmentation is:

(Annual Mechanical Costs) + (Annual Chemical Costs) = (Annual Cost of Mechanical/Chemical Snow Removal)

For the example of Boston, Massachusetts and assuming 16 snowfalls, only 11 of which require the application of chemicals, the following calculations are required:

MECHANICAL OPERATING COSTS:

LABOR:	(16 snowfalls/yr) x (2 man-hours/snowfall) x ($10/man hour)	=	$320
FUEL:	(16 snowfalls/yr) x (1 vehicle hours/snowfall) x (5 gal/vehicle hr) x ($1.20/gal)	=	$100
			$420 per year
OWNING COST*:			$105 per year
TOTAL MECHANICAL			$525 per year

CHEMICAL OPERATING COSTS:

LABOR:	(11 applications/yr) X (0.5 man-hour/application) x ($10/man-hour)	=	$55
CHEMICALS:	($4/gal) x (gal/1000 ft) x (1600 ft) x (11 applications/yr)	=	$70
OWNING COST**:	Purchase price of spreader	=	$20 to $60
TOTAL CHEMICAL		=	$125*
TOTAL ANNUAL COST:		=	$650

*$260 purchase price of the snow plow amortized over 3 years at 13% interest.
**Total cost does not include purchase price of spreader.

These equations are easily applied to an individual helipad. This method will allow operators to obtain a more accurate estimate of operating costs for their own unique chemical requirements and climate.

The equation used to calculate the annual operating costs of Earth Heat/Boiler pavement heatings systems is:

(Owning Costs) + (Operating Costs) =
(Annual Cost of Earth Heat/Boiler Pavement Heating System)

For the example of Boston, Massachusetts and utilizing the heat flux requirements given in the ASHRAE Guide, the following calculations are required.

OPERATING COSTS:

	FUEL:	$171.96
	ELECTRICITY:	343.89
	MAINTENANCE:	300.00
SUBTOTAL:		$815.85
OWNING COSTS:		$2516.52
TOTAL:		$3332.37

The derivation of the fuel cost is as follows:

The ground water of Boston is capable of supplying a constant 150 W/m^2 to the pad. This rate of heat flux will supply the pads total requirement 51.5% of the time when snow is falling according to the figures given in the ASHRAE Guide on yearly operating data for pavement heating systems. However, this still leaves the pad short by about 12.46 $KW \cdot HR/m^2$ per year. This is the amount which the boiler augmentation must supply.

$$12.46\ \frac{KW\cdot HR}{m^2} \quad \text{(to melt snow)}$$

$$+\quad 16.3\ \frac{KW\cdot HR}{m^2} \quad \text{(to keep pad idlying at a constant 33° all winter)}$$

$$28.76\ \frac{KW\cdot HR}{m^2}$$

$$28.76\ \frac{KW\cdot HR}{m^2} \times \frac{m^2}{39^2 in^2} \times \frac{144\ in^2}{ft^2} \times 1600\ ft^2 = 4356.5\ KW\cdot HR$$

$$(4356.5\ KW\cdot HR) \times \left(\frac{3.413\ btu}{W\cdot HR}\right) = 14.87 \times 10^6\ btu$$

$$(14.87 \times 10^6\ btu) \times \left(\frac{gal\ oil}{138{,}000\ btu}\right) = 107.7\ gal\ oil$$

(107.7 gallons of oil)(1.33 for stack loss) = 143.3 gallons of oil required

(143.3 gal oil) x ($1.20 per gal) = $171.96 per year on oil

The derivation of the electricity cost is as follows:

To achieve the 150 W/m^2 heat flux in the pavement 35 to 40 GPM of ground water must be flowing through the heat pipe manifolds. This water must be raised 10 ft above the level of the water table and will require two ¾ HP pumps. Each water pump is 220 V, single phase, and draws 7.2 amps.

$$(7.2 \text{ amps})(220 \text{ V}) = 1584 \text{ watts}$$

From the ASHRAE Guide it is found that the heating system will operate 1285 hours per year.

$$(1584\text{W})(1285 \text{ HR}) = 2035 \text{ KW}\cdot\text{HR}$$
$$4070 \text{ KW}\cdot\text{HR for 2 pumps}$$

Based on an electricity rate of \$0.0845/KW•HR the electricity cost is as follows:

$$(4070 \text{ KW}\cdot\text{HR}) \times (\$0.0845/\text{KW}\cdot\text{HR}) = \$343.89$$

The maintenance costs are estimated based on discussions with manufacturers and operators.

The owning costs are derived from manufacturer's estimates of system acquisition costs. See Table 3.11 for the specific breakdown.

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